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REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

(BLUE BOOK)

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JANUARY 15, 1971

Preliminary edition of

REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

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VOLUME II

ASTRONOMY

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PREFACE

The purpose of the preliminary edition of the "Reference Earth Orbital Research and Applications Investigations" set forth in this document is to:

a. Provide criteria, guidelines, and an organized approach for use in the Space Station and Space Shuttle Program Definition Phase and ancillary studies in designing a flexible, multidisciplinary orbiting space facility and logistics system.

b. Define a manned space flight research capability to be conducted in earth orbital Space Stations and Shuttles.

c. Provide a basis for potential follow-on programs.

The term "Functional Program Element" (FPE) used in this document describes a gross grouping of experiments characterized by the following two dominant features:

a. Individual experiments that are mutually supportive of a particular area of research or investigation, and

b. Experiments that impose similar and related demands on the Space Station Support Systems.

The research and applications investigations as set forth herein depart from a heterogeneous collection of individual experiments and are designed toward a "research facility" and "module" approach. The term FPE and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complementary module but would, however, permit flexibility in experiment planning.

Functional Program Elements and experiments covered in this document are envisioned for flight with the initial Space Station and the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be accomplished during the first few years of the Space Station and Space Shuttle have been described in detail in this document. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended.

This publication is applicable to all NASA program elements and field installations involved in the Space Station and Space Shuttle program.

The supply of this document is limited. Therefore, for those procurement actions involving only a certain portion (or portions) of this handbook, the cognizant NASA installations shall abstract from this handbook only such portions as apply to a given RFP or contract action.

This publication was prepared in conjunction with NASA Headquarters Program Offices and field installations involved in payload planning and with industry participation. It is an updated and revised version of the Candidate Experiment Program for Manned Space Stations, NHB-7150.xx, dated September 15, 1969 and the changes thereto dated June, 1970. These earlier versions are hereby cancelled.

The material contained in each volume has been produced under the guidance of Review Groups composed of scientific personnel at NASA Headquarters, MSFC, LaRC, MSC, LeRC, GSFC and ARC. The purpose of this effort was not only to revise and update the experiment programs but also to establish the Space Shuttle as well as the Space Station requirements.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie Operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II thru VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences & Manufacturing
Volume VII	Technology
Volume VIII	Life Sciences

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VOLUME 2

ASTRONOMY

INTRODUCTION

The functional program elements (FPE) in astronomy provide means for implementing a forward-looking long range program. Astronomical facilities and instruments located in space can reach the regions of the electromagnetic spectrum that are obscured or distorted by the earth's atmosphere. The functional program elements describe a coordinated multiwavelength, multisensor approach needed to locate, observe and interpret radiation from extragalactic, galactic, solar, and planetary sources in the different parts of the spectrum with spectral, angular, and temporal resolution not achievable from earth sites.

The X-ray Stellar Astronomy FPE will provide capabilities for extending the range of observable objects to extreme cosmological distances with improved angular, spectral (energy level), flux level, and polarization measurement resolution.

The Advanced Stellar Astronomy FPE will provide capabilities for greatly improved angular, spectral, photometric and polarization measurement resolution and accuracy in the $1\,\mu m$ to $0.09\,\mu m$ spectral range.

The Advanced Solar Astronomy FPE will provide capabilities for more continual observation in the $1.1\,\mu m$ (11,000 Å) to 2×10^{-10} m (2 Å) spectral region with better spectral, angular, temporal, and magnetic field resolution than is obtainable from large solar observatory sites on earth.

The Intermediate-Size UV Telescopes FPE provide an early means for testing stabilization, electronic imaging, and spectrometry approaches in a less costly size as well as continuing development of UV wide-field observations for diffuse or widely distributed sources.

The High-Energy Stellar Astronomy FPE provides pointed-observation capability for time-correlated (simultaneous) measurements in the energy spectrum from 0.1 keV to 30 GeV to obtain more complete information on the nature of physical processes occurring at these sources with improved energy, polarization, and temporal resolution.

The IR Astronomy FPE provides greatly improved capabilities for survey and detailed observation of cosmic, galactic, planetary, and diffuse IR sources in the $1000\,\mu m$ to $1\,\mu m$ spectral region at better sensitivites than possible from aircraft in the atmosphere or ground-based sites.

Representative astronomy objectives, experiments, facilities (telescopes or energy collectors), and instruments are presented, together with support requirements, in the six functional program elements. The representative experiment operations, facilities, and instrument package concepts are based on pre-Phase A studies and

proposals by scientists. Basic experiment performance values, as well as key support requirements, are presented to enable allocation and apportionment of subordinate functional requirements during definition studies of manned vehicles expected to support space astronomy observations and measurements in the period from 1976 to 1986. Multiple options are preserved to enable selection of cost-effective approaches in continuing system studies.

Assignments of crew skills from the following table have been made to enable experiment preparation, monitoring, operation, and output data selection, in addition to the astronaut capabilities required to prepare, checkout, deploy, maneuver, and recover the preferred free-flying astronomy facility vehicles.

Crew Skills

1. Biological Technician
2. Microbiological Technician
3. Biochemist
4. Physiologist
5. Astronomer/Astrophysicist
6. Physicist
7. Nuclear Physicist
8. Photo Technician/Cartographer
9. Thermodynamicist
10. Electronic Engineer
11. Mechanical Engineer
12. Electromechanical Technician
13. Medical Doctor
14. Optical Technician
15. Optical Scientist
16. Meteorologist
17. Microwave Specialist
18. Oceanographer
19. Physical Geologist
20. Photo Geologist
21. Behavioral Scientist
22. Chemical Technician
23. Metallurgist
24. Material Scientist
25. Physical Chemist
26. Agronomist
27. Geographer

SECTION 1

X-RAY STELLAR ASTRONOMY

1.1 GOALS AND OBJECTIVES

a. Identification, location and angular size of soft X-ray sources in the 10^{-10} to 10^{-8} meter (1 to 100 angstrom) spectral range;

b. Determination of the amount and distribution of the energy associated with such sources;

c. Detailed spectral information enabling determination of the physical mechanisms responsible for X-ray emissions;

d. Information enabling continuing technology development;

e. Simultaneous correlated observations and measurements enabling studies of image and spectral variations.

At the present time, theoretical and experimental studies, together with several highly successful exploratory rocket and satellite flights have demonstrated the feasibility of constructing an orbiting X-ray observatory with capabilities that would greatly exceed those of the 1970-1975 satellites. This observatory would employ precision image-forming X-ray telescopes equipped with high-resolution image analyzers, Bragg crystal spectrographs, and sensitive polarimeters. These instruments would achieve a degree of refinement in astronomical X-ray observations which has theretofore been achieved only in ground-based optical astronomy. The technical objective is an orbiting high-resolution X-ray observatory with maximum sensitivity, angular resolution, and spectral resolution.

Observations and measurements with sensors of lesser sensitivity and resolution indicate a certain prospect of fundamental astronomical discovery opportunities which provide assurance of a high return of immediately applicable information.

1.2 PHYSICAL DESCRIPTION

The X-ray astronomy facility consists of six independent X-ray collection and direction-sensing assemblies: (a) a high resolution (1000 cm^2) X-ray telescope, (b) a large area, moderate resolution X-ray telescope, (c) a proportional counter array, (d) a scintillation counter assembly, (e) a crystal spectrograph, and (f) a transient X-ray phenomena detector. Although the assemblies are independent of each other, correlation of the data when all six are operated simultaneously yields data over an energy spectrum from about 1 to 200 fJ (0.1 keV to 10 keV or 100Å to 2Å) and provides a basis for

analysis of interfering signals. Table 1-1 is a summary of the predicted types of experiments versus the large facility items as well as individual special or alterable experiment equipment which may be periodically changed or updated at the insistence of the prime investigators.

Figure 1-1 shows an ideal arrangement of the major assemblies in some typical supporting vehicle. Masses and volumes are given in Table 1-2; values listed do not include margins for launch loads, safety, or reliability.

The principal instruments are two X-ray telescopes which utilize the efficient reflection of X-rays at grazing incidence to form high resolution images of the X-ray sky. The grazing incidence requirement for efficient reflection unfortunately results in surfaces which are approximately parallel to the incident radiation, and therefore it becomes difficult to utilize efficiently the telescope aperture because the mirror wall materials must consume part of the available area. From previous experience, X-ray telescope analysts have concluded that the requirement of maximum collecting area and highest angular resolution are not compatible and that two telescopes would be required. Fortunately, the experiments to be performed can be divided into those more sensitive to area and those more sensitive to angular resolution.

1.2.1 HIGH RESOLUTION (1000 cm^2) X-RAY TELESCOPE ASSEMBLY. The High Resolution X-Ray Telescope Assembly consists of a nested mirror array with provisions for mounting aspect sensor optics parallel to the mirror axis, structure relating the mirror to the focal plane, an optical bench in the region of the focal plane, and an experiment interchange assembly. Instruments utilized with the telescope are an aspect sensor (optics and detector), an imaging detector (image converter/intensifier), a transmission grating, and a focusing-circle type spectrometer. The high resolution mirror is a paraboloid-hyperboloid type device, as shown in Figure 1-2, in which X-rays are first focused at the common paraboloid-hyperboloid focal plane but with severe comatic distortion; the X-rays are then focused from the common focal plane to the near focal plane of the hyperboloid and most of the distortion is compensated.

The tentative optical design includes five concentric nested surfaces to increase the effective area of the telescope. Each mirror is essentially a scaled-up copy of the present S-054 experiment mirrors, and therefore can be expected to have the same limiting theoretical resolution. These results are shown in Figure 1-3. The actual resolution will depend upon the surface finish and contour accuracies obtained. Mirror parameters are summarized in Table 1-3.

All mirrors have an axial length of 110 cm (44 in.) – 55 cm (22 in.)/segment, and a focal length of 610 cm (240 in.). The final optical design of the mirrors should include slight modifications of the paraboloid-hyperboloid geometry to improve the off-axis resolution.

Table 1-1. Summary of Equipment/Instrumentation Versus Experiments

Experiment Class	A High Resolution (1000 cm^2) X-Ray Telescope	B Large Area (5000 cm^2) Moderate Resolution X-Ray Telescope	C Proportional Counter Array	D Scintillation Counter Assembly	E Flat Crystal Spectrograph Assembly	F Transient X-Ray Phenomena Detection Array	1 Aspect Optics	2 Aspect Detector	3 Imaging Detector	4 Transmission Grating	5 Filter Wheel	6 Spectrometer (Crystal)	7 Solid State Detector	8 Multianode Prop. Counter	9 Mosaic Crystal	10 LiH Polarimeter	11 Graphite Polarimeter	12 Proportional Counter Detectors	13 Anticoincidence Counters	14 Pulse Shape Processors	15 Pulse Height Analyzers	16 Passive Collimators	17 Scintillation Detectors (Crystal)	18 Anticoincidence Shield	19 Radioactive Calib Source	20	21
	Facility Items						Special Experiment Assemblies and Equipment																				
Hi Res. X-Ray Telescope Exps.	•						•	•	•	•	•	•															
Aspect Sensing							•	•																			
Hi Res X-Ray Imaging	•						•	•	•	•	•																
Hi Res X-Ray Spectroscopy	•						•	•				•													•		
Large Area Moderate Resolution X-Ray Telescope Experiments		•					•	•					•	•	•	•	•								•		
Max Sensitivity Detection		•											•												•		
Position-Sensitive Proportional Counter Imaging		•												•											•		
Mosaic Spectrometry		•												•	•										•		
Polarimetery		•														•	•								•		
Large Proportional Counter Array Experiments			•				•	•										•	•	•	•	•			•		
Cross Calibration			•															•	•	•	•	•			•		
Strong Signal Time Variability			•															•	•	•	•	•			•		
Scintillation Counting Experiments				•			•	•													•		•	•	•		
Crystal Spectrograph Exps					•		•	•																	•		
Higher Energy Spectroscope																											
Doppler Shift, Source					•		•	•																	•		
Temp/Velocity Meas.					•		•	•																	•		
Transient X-Ray Phenomena Detection						•																			•		

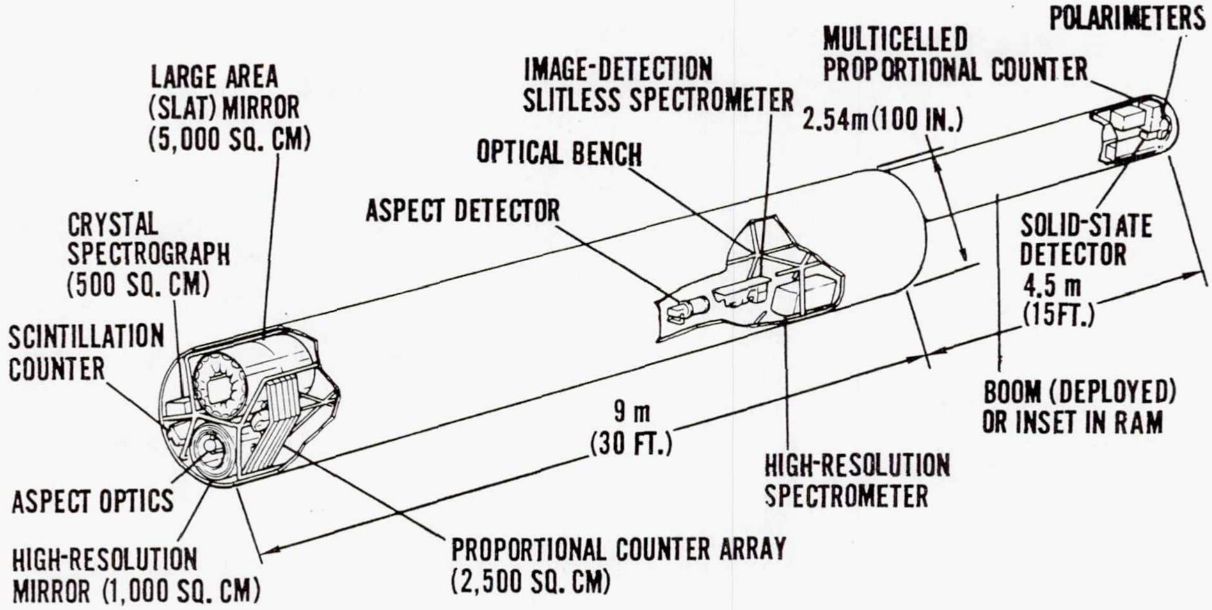


Figure 1-1. Arrangement of Major X-ray Astronomy Equipment

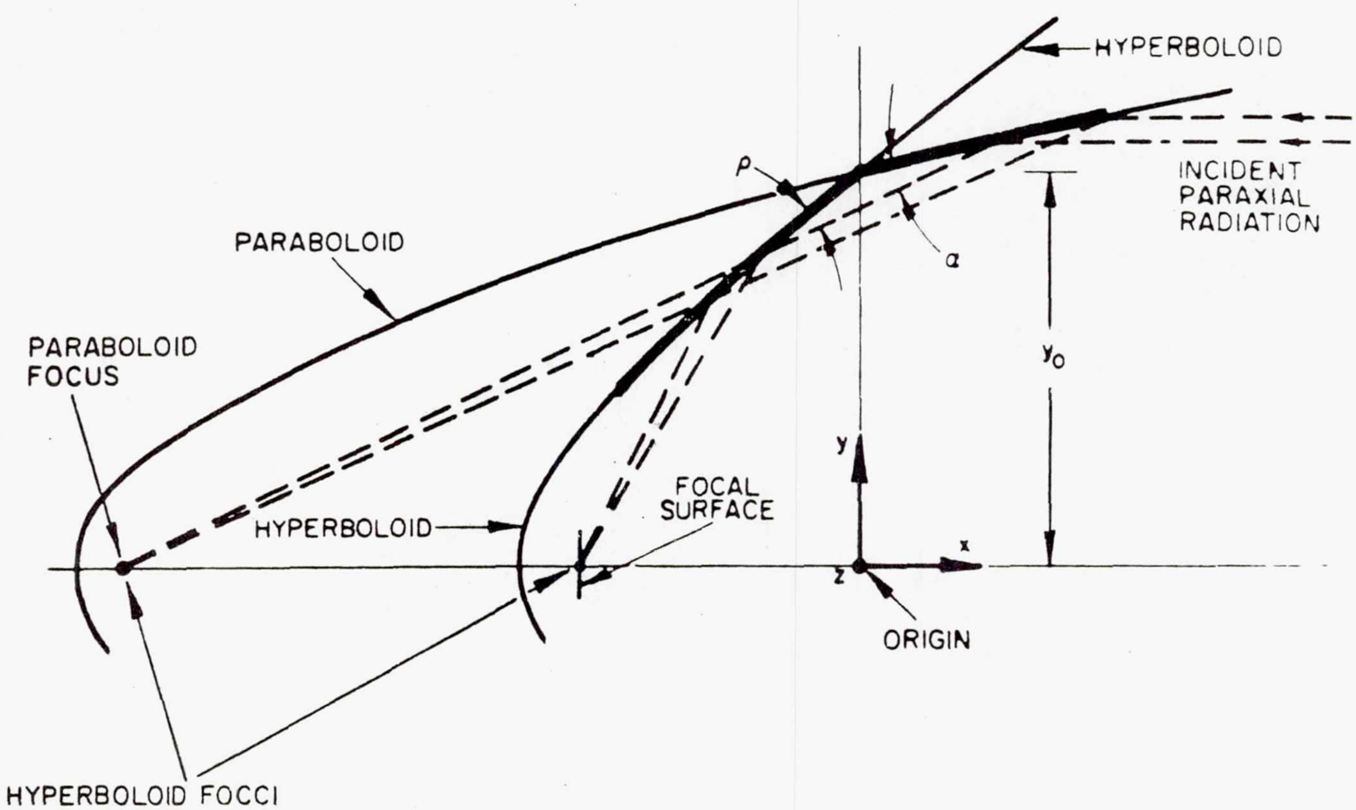


Figure 1-2. Schematic Cross-Section of the High Resolution X-ray Telescope

Table 1-2. Experiment Weights, Volume, and Envelope Estimates

FACILITY ITEM	EXPERIMENT	MASS† kg (lb): FIXED POSITION	MASS† kg (lb): RELOCATABLE ELECTRONICS	MASS† kg (lb): TOTAL kg	VOLUME* † m^3 (ft^3): FIXED POSITION	VOLUME* † m^3 (ft^3): RELOCATABLE ELECTRONICS	VOLUME* † m^3 (ft^3): TOTAL m^3	EQUIVALENT OCCUPANCY ENVELOPE† (Dimensions in Meters): FIXED POSITION	EQUIVALENT OCCUPANCY ENVELOPE† (Dimensions in Meters): RELOCATABLE ELECTRONICS	LOCATION FOR FIXED ITEMS
1.2.1	High Resolution Telescope							(1.02D×8.8L)*		
	Mirror	680 (1500)	—	680	2.5 (87.7)		2.5	1.02D×2.26L	—	Outer End
	Optical Bench	318 (700)	—	318	2.6 (91.7)		2.6	0.9×0.96×2.95L	—	
	Experiment Interchange Apparatus	22.5 (50)	4.5 (10)	27	0.05 (2.02)	0.004 (0.16)	0.05	0.3D×0.66	0.12×0.15×0.26	Focal Point
	Aspect Lens	16 (35)	—	16	0.02 (0.6)	—			—	Outer End
	Aspect Detector Assembly Structure	32 (70)	16 (35)	48	0.005 (0.19)	0.014 (0.5)	0.02	0.13×0.13×0.33	0.15×0.15×0.61	Focal Area
	Imaging Detector Assembly	32 (70)	27 (60)	59	0.01 (0.4)	0.03 (1)	0.04	0.12×0.12×0.71	0.06×0.3×0.61	Focal Point
	Spectrometer Detector Assembly	25 (56)	18 (40)	43	0.17 (6.1)	0.014 (0.5)	0.18	0.47×0.4×0.96	0.15×0.15×0.61	Focal Area
	Filter Wheel	14 (30)	—	14	0.03 (0.98)	—	0.03	0.38D×0.24	—	Front of Focal Area
	Grating Assembly	14 (30)	—	14	0.17 (6.06)	—	0.19	1.01D×0.2L	—	Front of Mirror
	Subtotal for Hi-res Experiments			194	0.475 (16.93)	0.058 (2.00)	0.54			
	Total for Hi-res Telescope + Exps			1219	10* (353)*	0.062 (2.16)	10.06*	1.02×9.1L		
1.2.2	Large Area Telescope							(1.5D×13.7L)		
	Mirror - Supporting Structure (also structure for Hi-res mirror)	1360 (3000)		1360	4.2 (150)	—	4.25	1.34D×3L		Outer End
	Optical Bench and Boom**	726 (1600)	—	726	6.4 (225)	—	6.37	1.34D×4.6L		
	Experiment Interchange Apparatus	45 (100)	—	45	0.55 (19.5)	—	0.55	0.61D×0.66		At Focal Point
	Subtotal for Large Area X-ray Telescope			2131	21* (742)*		21*	1.02×13.7		
	Solid State Detector	22.5 (50)	7 (15)	29.5	0.006 (0.22)	—	0.006	0.28×0.15×0.15		
	Refrigeration for Solid State Detector	—	—	—	—	0.08 (3)	—	0.3×0.3×0.9		
	Imaging Detector (Proportional Counter)	7 (15)	27 (60)	34	—	—			—	
	Objective Crystal (for Mosaic Spectrometer)	295 (650)	—	295	1.29 (45.6)	-	1.29	0.4×1.3×2.4		Front of Large Telescope
	G Polarimeter	15 (34)	—	15	0.007 (0.25)	—	0.007	0.19D×0.25L	—	
	LiH Polarimeter	17 (38)	22.5 (50)	39.5	0.007 (0.25)	0.03 (1)	0.035	0.19D×0.25 L	0.15×0.3×0.61	
	Total for Large Area Telescope Exps			413	1.31 (46.32)	0.11 (4)				
	Large X-ray Telescope + Exp Instruments			2544	21 (742)	0.11 (4)	21.1*	1.02×13.7L		
1.2.3	Large Proportional Counter Assembly	75 (166)	14 (30)	89	0.245 (8.66)	0.03 (1)	0.275	1.01×0.63×0.38	0.15×0.3×0.61	
1.2.4	Scintillation Counter	130 (286)	14 (30)	144	0.2 (7)	0.03 (1)	0.23	0.56×0.5×0.76	0.15×0.3×0.61	Outer End
1.2.5	Flat Crystal Assembly (500 cm^2) Crystal Spectrograph	53 (117)	9 (20)	62	0.56 (19.8)	0.01 (0.5)	0.57	0.5×0.72T×1.55	0.15×0.15×0.61	Next to X-ray Telescope Mirror
1.2.6	Transient X-ray Phenomena Detector	145 (320)	9 (20) 4 each	181	0.19 (6.75)	0.01 (0.5)	0.2	4 ea 1/2 (0.46×0.46×0.46)	4 ea (0.15×0.15×0.61)	Periphery of Vehicle
	GRAND TOTALS	4040 (8906)	195 (430)	4239 (9346)	32.2 (1136.2)	0.26 (9.16)	32.5 39.4	2.59D×9L 2.59D×4.5L		

* Volume includes space not occupiable by other devices, such as the intervening geometry required for focusing.
** Alternatively, the "boom" may become a cylindrical tube 4.5m long inset into the supporting vehicle.
T = Truncated equilateral triangle with base = 0.76m, truncat. Ht. = 0.5m.
† This tabulation contains typical numbers which are based on proposal type information from scientists.

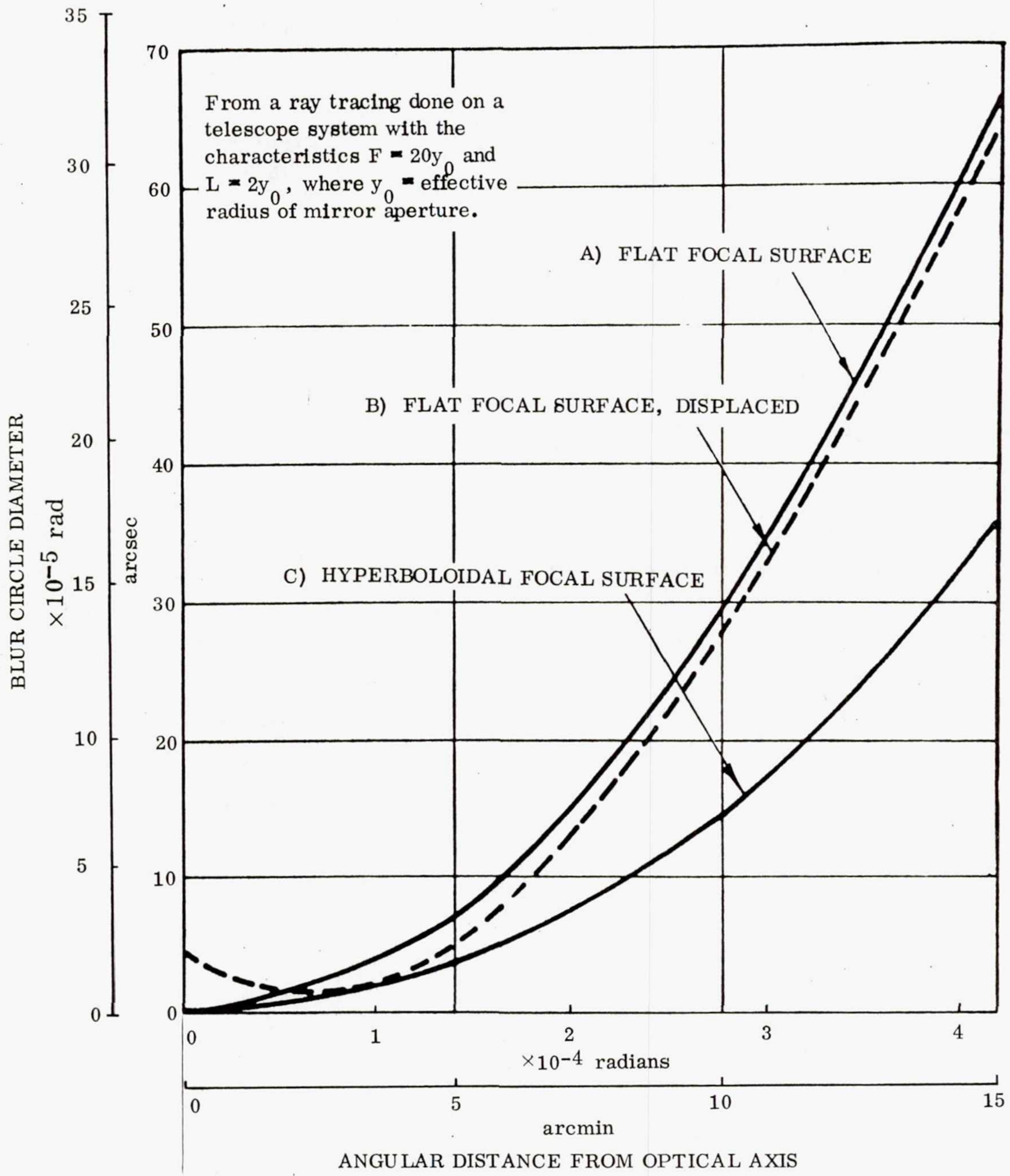


Figure 1-3. Total Blur Circle Diameter Versus Angular Distance Optical Axis

Table 1-3. High Resolution X-ray Telescope Mirror Parameters

Mirror Diameter (H-P Intersection) m (in.)	Grazing Angle For On-Axis Rays (mrad)	Geometrical Effective Area For Axial Rays (cm^2)
0.895 (35.24)	18.32	287.9
0.846 (33.29)	17.31	257.0
0.796 (31.33)	16.29	227.7
0.746 (29.37)	15.28	200.1
0.696 (27.41)	14.28	174.5
Total		1147.2

A calculation of the effective area of the telescope as a function of wavelength for surface of nickel, fused silica, and platinum is shown in Figure 1-4. These values depend upon the real and imaginary parts of the index of refraction for each material. The real part was calculated from the Kramers-Kallmann-Marx expression which is adequate except for regions near absorption edges where the expression becomes singular because of certain approximations in its derivation. The imaginary part only depends upon the mass absorption coefficient and can be directly measured; unfortunately, the experimental data does not completely span the wavelength interval of interest, and

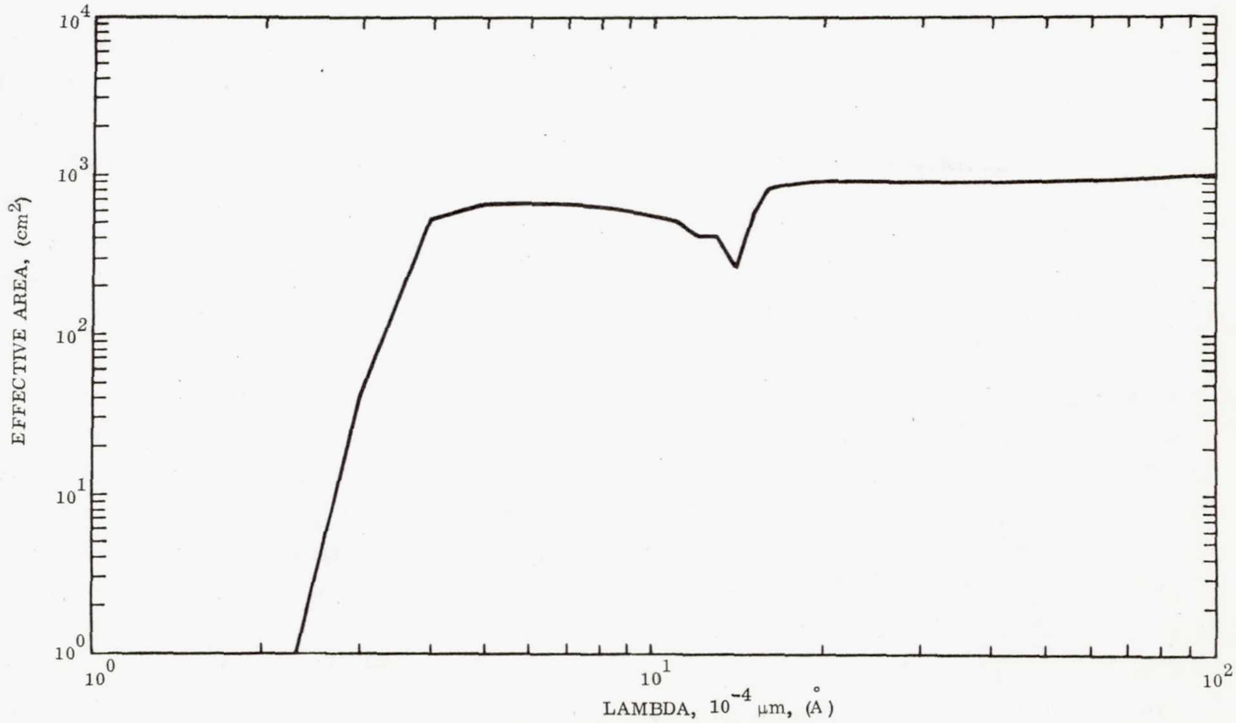


Figure 1-4. High Resolution X-ray Telescope Effective Area Versus Wavelength

empirical models must be used. More accurate expressions for both parts of the index of refraction are available, and a better calculation should be made when the final configuration and material are chosen; the results, however, will not differ substantially from this calculation except for regions near absorption edges where the reflectivity will be greater than calculated here. In practice, the reflectivity will also depend upon the surface finish in a wavelength-dependent fashion. The plot indicates that the high resolution X-ray telescope is potentially usable from 3×10^{-10} m to at least 10^{-8} m (3 Å to 100 Å), and possibly to a longer wavelength.

1.2.2 LARGE AREA (5000 cm^2) MODERATE RESOLUTION X-RAY TELESCOPE. The large area moderate resolution ($\sim 5 \times 10^{-5}$ rad or 10 arcsec) telescope will have an effective area of 5000 cm^2. The X-ray telescope assembly consists of the large-area mirror, optical bench, boom, and experiment interchange apparatus. At least four sets of experiment instruments will be sequenced into the focal area, one at a time. Because of the uncertainty of the effective collecting area of the high resolution instrument, it was found to be essential that the orbiting X-ray observatory contain another focusing instrument with a high effective collecting area even if the angular resolution is somewhat sacrificed. The Baez-type X-ray telescope has been selected as a maximum sensitivity X-ray energy collector. The reason for this is that the individual focusing elements can probably be made in the form of flat sheets of glass which can be fabricated and polished with the best possible optical techniques. Also, since this instrument employs modular construction, each glass plate can be separately tested for reflectivity before it is installed in the telescope. This belief is based on the hope that the curvature required in these elements can be obtained by elastically deforming the glass plates in a suitable holder.

The question of whether or not the above can be achieved depends in part upon the focal length of the instrument. The longer the focal length the less curvature is required, and the more likely it becomes that optical flats can in fact be used as the basic element. In view of this it is extremely important that the spacecraft be large enough to accommodate an instrument of at least 13.5 m (45-ft) focal length. Many laboratories have succeeded in obtaining the theoretically predicted X-ray reflection coefficient for suitably coated optical glass plates, and there seems to be no question whatsoever that the Baez telescope would in fact have a very high X-ray reflection coefficient.

According to current estimates, it is reasonable to assume that the geometrical aberrations of this lens will correspond to an angular size of 1/22 of the angle that the starlight makes with the axis of the telescope, and in addition it appears realistic to think in terms of a 5×10^{-5} to 10×10^{-5} radian (10 to 20 arcsec) resolution for objects on the axis of the telescope. This is more than adequate for purposes of polarimetry and spectroscopy. The tentative design for the large-area mirror incorporates the principle of a Baez device (Figure 1-5); the incident ray successively strikes two parabolas at approximately right angles to one another and at equal angles to the plane including their modules (Figure 1-6); each module consists of a set of approximately

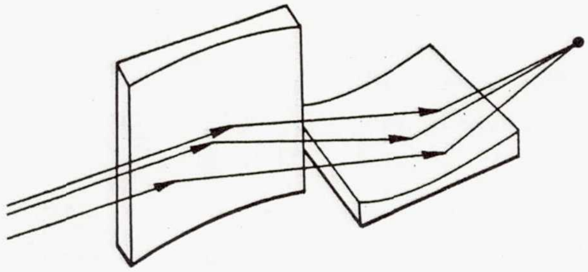


Figure 1-5. Baez Geometry for Large Area Telescope

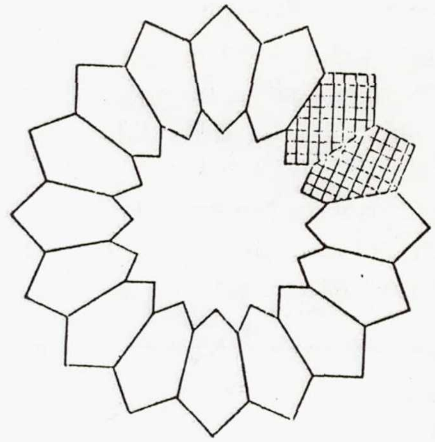


Figure 1-6. Large-Area Telescope Modular Construction

parallel parabolic sheets followed by a similar set at right angles to the first. The Baez design has been chosen because of the possibility of producing the common-design individual segments at lower cost than the production of individually designed pieces; this concept does, however, result in a longer focal length for the same collecting area and somewhat poorer resolution than the paraboloid-hyperboloid mirrors. In the present design, the radius of the blur circle will be approximately 1/22.5 times the distance off axis. There are also smaller correction terms, the largest being of order of 10^{-5} rad (2 arcsec).

The effective area and weight of the mirror depend critically upon the thickness of the surface required to maintain the desired contour accuracy. The following results are obtained:

Edge Thickness (cm)	Edge Thickness (in.)	Effective Area (cm^2)	Volume of Wall Material (m^3)	Volume of Wall Material (in^3)
0.127	0.05	6,623	0.402	24,550
0.254	0.1	5,036	0.494	30,140

The worst-case mass estimate, assuming fused-silica mirror segments with 0.254 m (0.1 in.) edges, is 1360 kg (3000 lb) including an estimated 272 kg of structure. It may be possible to greatly increase the effective area by making the surfaces out of very thin, highly polished, coated silicon sheets; in this case, the structure would be larger in order to maintain the desired contours but the total weight should be reduced.

The focal length of the mirror is 13.5 m (45 feet) and the grazing angles vary from 7.2 to 17.4 milliradians. The focal length is longer than some of the proposed launch vehicles. The large telescope instruments will have to recess into the supporting vehicle or extend as shown. The optical bench and other support structures will weigh about 725 kg (1600 lb).

A calculation of the expected effective area versus wavelength is given in Figure 1-7. This calculation is subject to the same difficulties as discussed previously for the High Resolution Telescope.

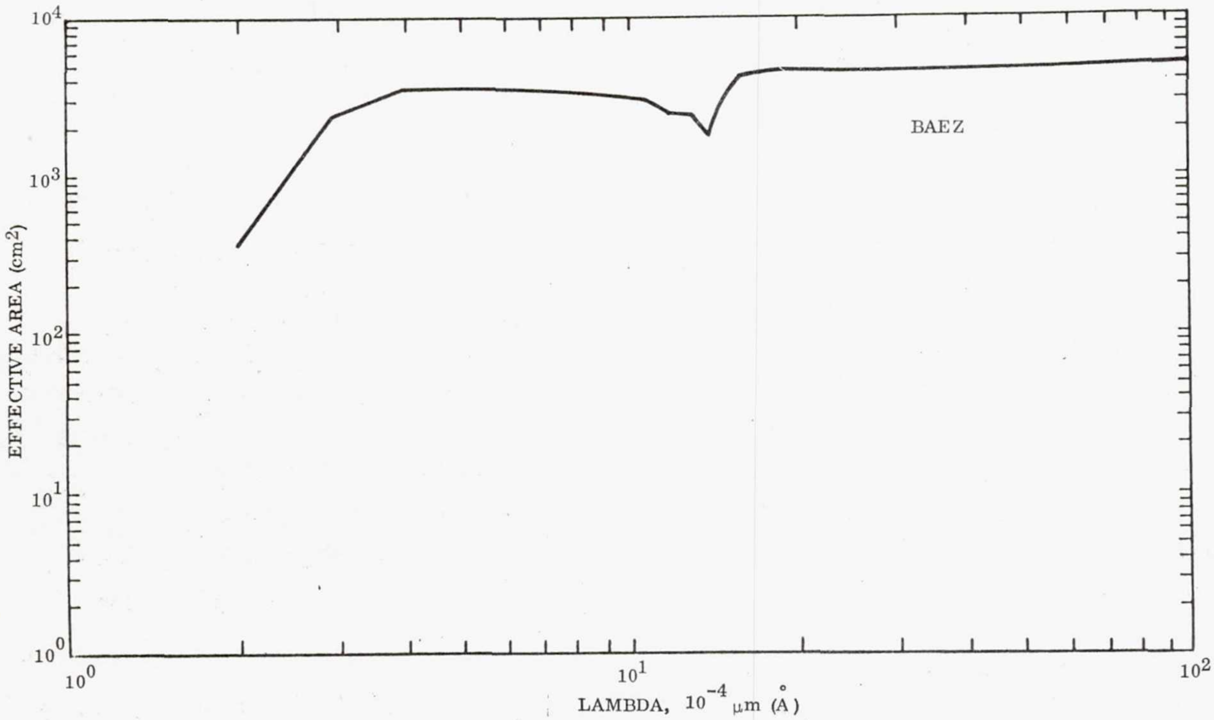


Figure 1-7. Large X-ray (Baez) Telescope Effective Collector Area Versus Wavelength

1.2.3 PROPORTIONAL COUNTER ARRAY (2500 cm^2). The proportional counter array has been included in the X-ray Stellar Astronomy Group to provide cross-calibration to the other telescopes and instruments in the 16 to 160 fJ (1 to 10 keV) range. The collecting area will be about 2500 cm^2 and the collimator acceptance angle about 1°. The array will be located at the group aperture in parallel with the other energy collectors as shown in Figure 1-1. Some of the electronics will be located in the supporting vehicle near the X-ray telescope focal plane.

The proportional counter detectors, as well as the anticoincidence counters, are divided into two independent portions, each of which has its own power supplies and processing electronics. The processing electronics (Figure 1-8) portion is reasonably conventional and utilizes anticoincidence as well as pulse-shape-discrimination

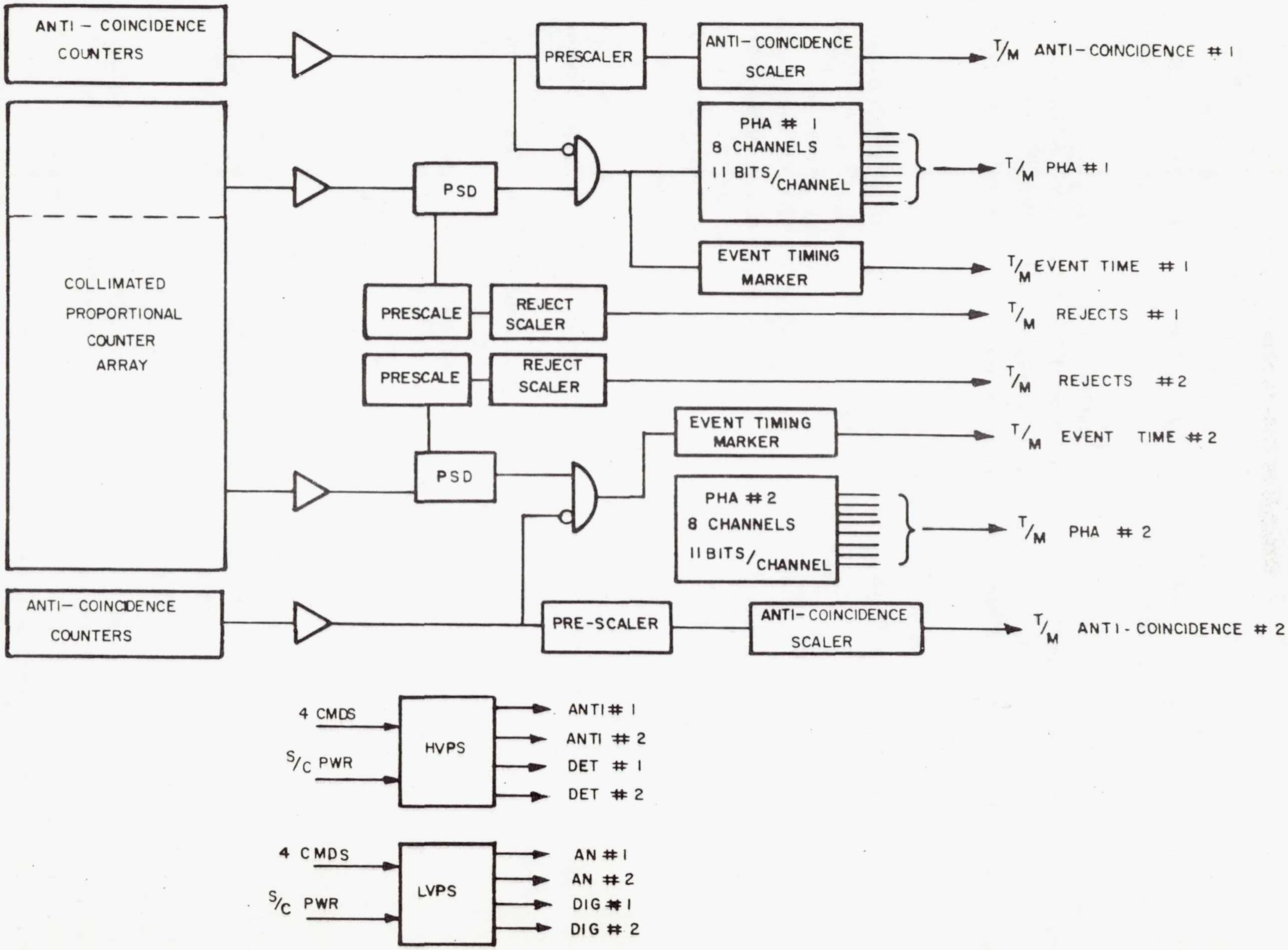


Figure 1-8. Proportional Counter Array

rejection techniques. Rejected events due to PSD and anticoincidence are accumulated respectively in separate scalers. Prescalers assure a reasonable telemetry rate for these quantities. An Event Time Marker provides a pulsar mode and identifies whether or not an event has occurred within the immediately preceding one millisecond time window. Periodically, a code word and time will be inserted in place of the data.

Since parts of this instrument will be at two locations in the assembled group, Table 1-4 enables an estimate of mass volume required at each location. Relocatable electronics near the X-ray telescope focal area may be periodically retrofitted or interchanged. Access of man to instrument portions at the aperture is desired but is difficult to provide.

Table 1-4. Proportional Counter Array Breakdown

Experiment Equipment Breakdown	Mass kg	(lb)
Power Supplies	3.6	(8)
Sensor Equipment		
Counters and Pre-Amps	36.7	(81)
Collimator	14	(30)
Structure	19.1	(42)
Electronics	2.2	(5)
Total Mass at Aperture	75.6	(166)
Relocatable Electronics	13.6	(30)
Total for Experiment	89	(196)
Cables (Supplied by Vehicle)	32	(70)

1.2.4 SCINTILLATION COUNTER ASSEMBLY. The scintillation counter assembly is included to extend the energy acceptance of the system, for it is often found that measurements over a small portion of the spectrum are consistent with a variety of special forms if each form has a few adjustable parameters.

The proposed detector is quite conventional. Nine standard 100-cm NaI crystal-phototube assemblies are contained in an anticoincidence counter and passive shield. A 0.1-radian (5°) FWHM passive collimator preceeds each crystal. The electronic system will allow up to 125 events per second, each event being coded with 3 amplitude and 3 time bits. In addition, all acceptable events are stored in an 8-channel (256 events/channel) pulse height analyzer which is read out once per second. The anticoincidence counter rate is also read once per second.

Since part of the assembly is located at the X-ray Stellar Astronomy group aperture and part near the X-ray Telescope focal plane about 17 meters (55 feet) away, an equipment breakdown is given in Table 1-5. Fixed experiment volume is 0.198 m^3 (7 ft^3) in an envelope of $0.56 \times 0.506 \times 0.76$ m ($1.83 \times 1.66 \times 2.5$ ft).

Table 1-5. Scintillation Counter Assembly Breakdown

Experiment Equipment Breakdown	Mass kg	(lb)
9 Modules		
Collimator	3	(6.5)
Crystal	0.6	(1.3)
Phototube & Pre Amps	1.8	(4.0)
Total Per Module	5.4	(11.8)
× 9 Modules	48.5	(107)
Anticoincidence Shield		
Scintillator	14	(30)
Metal	54	(120)
Phototubes & Pre-Amps	9	(20)
Power Supplies	4.5	(10)
Total for Aperture Equip.	130	(287)
Relocatable Electronics	14	(30)
Experiment Total	144	(318)
Cables (35) Supplied by Veh.	16	(35)

1.2.5 FLAT CRYSTAL SPECTROMETER. A collimated flat crystal spectrometer has been included to study the astronomically important emission lines such as Fe^{24} and Fe^{25} which are beyond the high energy cutoff of the telescopes. The system consists of a collimator ($\sim$500 cm^2, 1×10^{-2} rad, 36 arcmin FWHM acceptance), flat crystal, and proportional counter detector. The proportional counter is surrounded by anticoincidence counters to reduce the charged particle background. The device concept is shown in Figure 1-9.

A lithium fluoride crystal would be used because of its high peak reflectivity (> 40%) and a rocking curve somewhat broader than the natural line widths of the lines to be observed. Because of these properties it is highly efficient for observations of high energy X-ray lines. The 4.026×10^{-10} m (4.026 Å) 2d spacing of LiF and its high second-order reflectivity allows the 3-18 keV region to be observed.

The flat crystal spectrometer will complement well the high resolution spectrometer used with the 1000 cm^2 X-ray Telescope. Comparisons of temperatures, velocities, line strengths and relative abundances obtained from the two spectrometers will be important in understanding X-ray production mechanisms and the nature and evolution of these sources. X-ray line emission is important in the 10^{-10} to 6×10^{-9} m (12.4 keV to 2 keV or 1-60 Å) region. Because grazing-incidence telescopes do not work in the lower-wavelength end of this region, the flat crystal spectrometer is proposed in order to obtain complete spectroscopic investigations of X-ray sources.

The spectrograph crystal and proportional counter detector are mounted on a mechanical drive system which maintains the proper relative orientation of both crystal and detector during the range of scanning angles. The drive for this mechanism is a magnetic detent gear head stepping motor providing a crystal rotation of 4.85×10^{-6} rad (1 arcsec) per step. The total scan will require 12.5 minutes. A 15-bit shaft encoder mechanically coupled to the crystal will monitor its angular displacement with a resolution of 2.4×10^{-5} rad (5 arcsec).

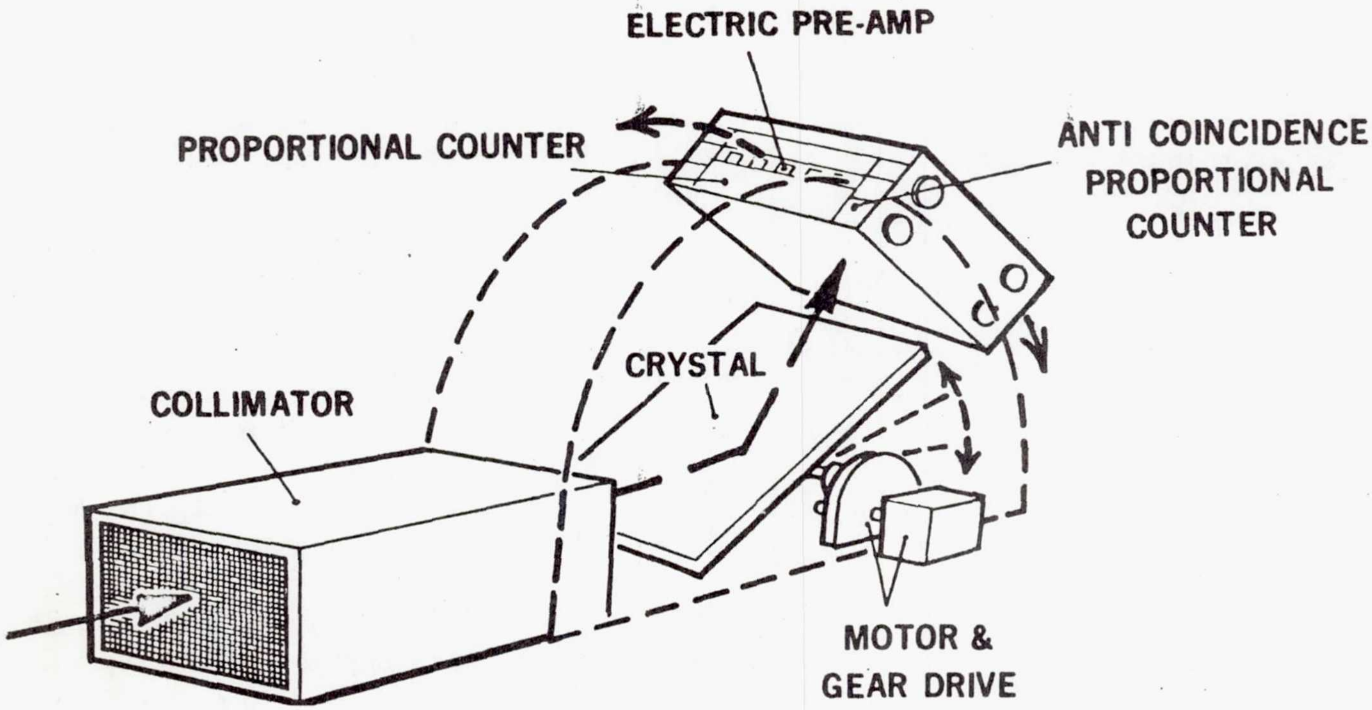


Figure 1-9. Crystal Spectrograph, 500 cm^2

A scan programmer permits selection, via up-link data commands, of the crystal scan start and stop angles. A "Scan Ident" output will provide data for establishing event time.

The detector, a collimated proportional counter, will utilize pulse shape discrimination and anticoincidence techniques to filter undesired events. The occurrence of an event will enable the shaft encoder reading to be stored and subsequently telemetered. Figure 1-10 contains a block diagram of the electronics.

During a small portion of the crystal scan, the proportional counter detector will be illuminated by a radioactive source. This will allow for calibration as well as verification of gross spectrograph operation.

Mass characteristics of the Flat Crystal Spectrometer are given in Table 1-6.

1.2.6 TRANSIENT X-RAY PHENOMENA (ALL SKY) DETECTION ARRAY. Figure 1-11 shows an arrangement of four detector arrays placed concentrically inside a single gas volume for 2π steradian coverage with considerable overlap. Full all-sky ($4\pi \times$ steradians) coverage can only be achieved with two such systems with a total of eight counters and about 8×10^3 resolution elements, but the four-panel array is adequate for low earth orbits. For the X-ray stellar astronomy functional program element (FPE) grouping of collector instrument assemblies, the four detector arrays will be located in individual gas cells $\pi/2$ rad (90 deg) apart around the cylindrical telescope shroud.

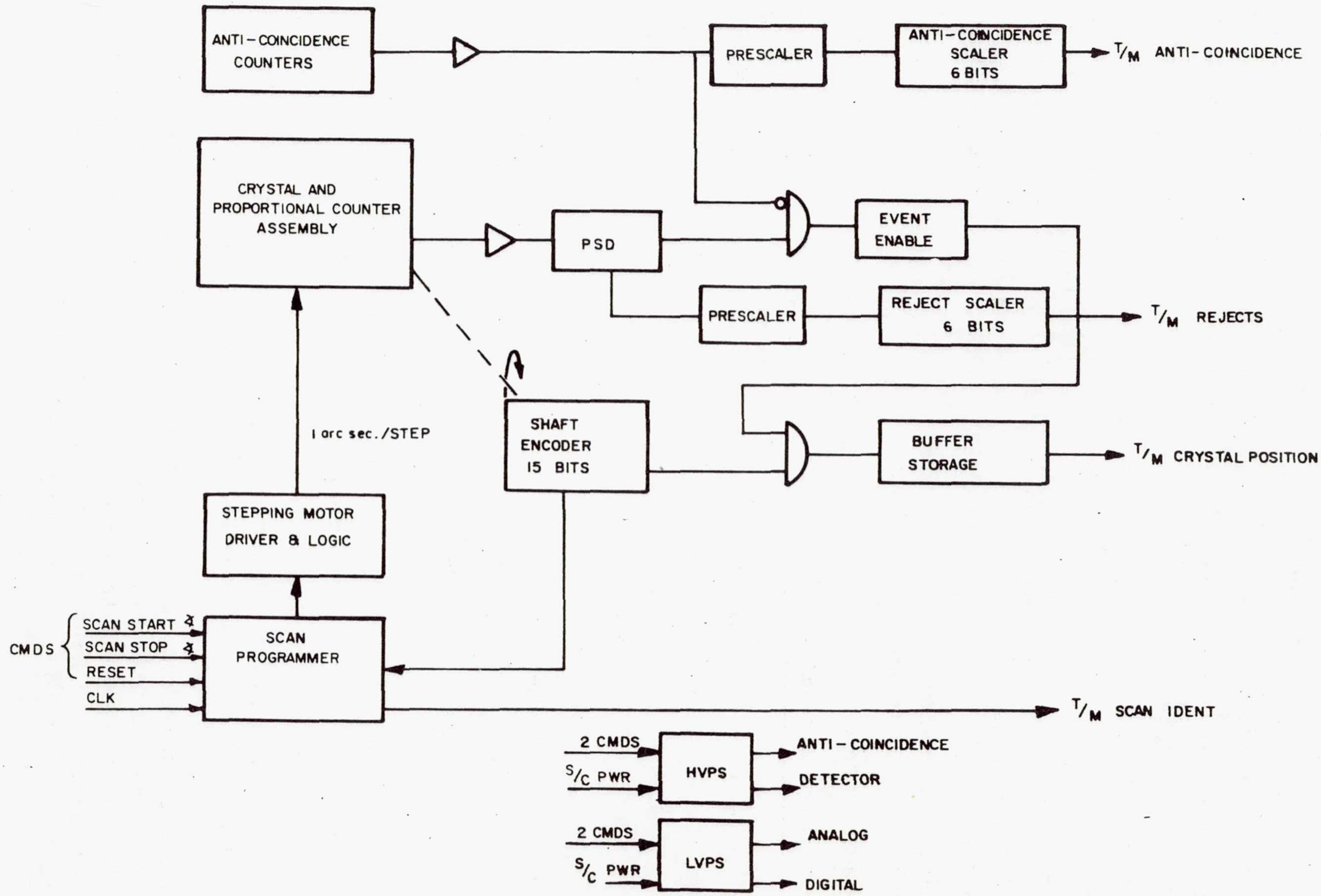


Figure 1-10. Flat Crystal Spectrograph

Table 1-6. Flat Crystal Spectrometer Mass Characteristics

Experiment Equipment Breakdown	Mass kg	(lb)
Collimator	8	(18)
Crystal Drive Assembly	17	(37)
Structure	18	(40)
Detector Assembly	10	(22)
Total Weight (Outer Aperture End)	53	(117)
Relocatable Electronics (Near telescope focal plane)	9	(20)
Experiment Total	62	(137)
Cables (supplied by vehicle)	16	(35)

A multi-anode proportional counter, similar to the one used in the imaging scheme described earlier, is suited for transient X-ray source direction finding and identification. Appropriate collimation must be provided so that a point X-ray source within the field of view appears roughly on only one of the counter's resolution elements. This may be accomplished in a manner which parallels the concept of the pinhole camera, as illustrated in Figure 1-12. The field of view is within a 1.05 rad (60 deg) cone and is subdivided by means of the multiple anode construction and by differential information obtained through charge collection from both ends of the resistive anodes. The proposed construction calls for each resolution element to correspond to about 15 square degrees near the center of the field of view, with about 1000 such elements per counter.

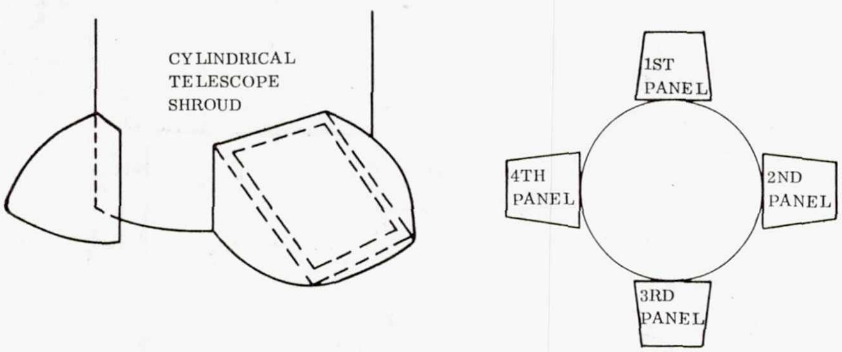


Figure 1-11. X-Y Transient Detection Array Combination for 2π Steradians Coverage

The sensitivity attained by this detector will depend on its response to the diffuse X-ray radiation and on the intrinsic background (vis., not subject to collimation).

A few details of the detection array are outlined in Figure 1-12. Each detector is (tentatively) comprised of two back-to-back layers of 32 anodes and corresponding ground wires. All anodes of the second layer are tied in parallel and used in anti-coincidence with the anodes of the first layer. Anode grouping will be used to reduce the number of pre-amplifiers needed per counter.

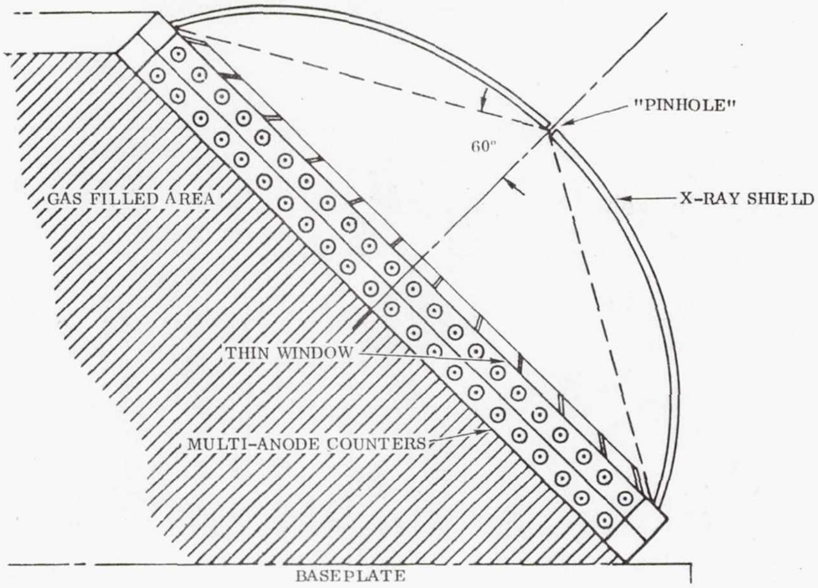


Figure 1-12. X-Ray Transient Detector Array Panel

Gas pressure is maintained by means of X-ray transmission windows supported by circular collimator ribs. The latter are designed for maximum transmission at the corresponding angles of incidence. Estimated mass per array panel is 45.4 kg (100 lb).

1.3 EXPERIMENT REQUIREMENTS SUMMARY

Experiment requirements derived in Section 1.4 are summarized in Table 1-7

1.4 EXPERIMENT PROGRAM

Three categories of immediate experimental effort can be defined for X-ray stellar astronomy. These include surveys of selected regions in the sky, detailed studies of individual objects and long-term monitoring of certain sources. To obtain capability for accomplishing the desired observations, six groups of improved instruments and techniques complementing each other in space will be experimentally developed and tested, and observation opportunities systematically exploited. Even though free-flying astronomy experiment support vehicles in space using guide-star trackers probably will be able to achieve pointing stabilities with moderate sized guide-star tracker and aspect optics to better than 5×10^{-6} rad (1 arcsec), the imaging portions of the X-ray telescope will enable further electronic stabilization of X-ray images converted into visible light or output data signals.

1.4.1 HIGH RESOLUTION X-RAY TELESCOPE EXPERIMENTS

1.4.1.1 Scientific or Technical Objectives. The high resolution X-ray telescope experiments will be used to obtain information for detailed studies of moderate-strength

Table 1-7. X-Ray Stellar Astronomy Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.1 Hi Resolution X-ray Telescope Experiments	1218 (2686)	10 (355.2)	1.02 D x 9.2L (3.35D x 30L)	Average: 172 Peak: 254 Standby: 72 Total: 557.3 watt-hours	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Observational Astronomers	Temp Limits: 272 to 274°K Ops Atmosphere: 1.33×10^{-4} N/m^2 (< 10^{-6} Torr) Gravity Level: < 10^{-4} g, ops Radiation Sensitivity: 1 mrad/hr	Setup: 2.5 Ops Cycle: 1.6 to 3.24 Maintenance: 2.5	Picture Elements Per Image: 1,048,576 Images/Sec: 16, 24, 256, or 1024 Digital Picture Data: 1.19×10^8 bits/image Internally Processed Non Imaging Data: Command 40 bps Science/Exps: 3.625×10^4 bps Housekeeping: 415 bps	Pointing Accuracy: 2.9×10^{-4} rad (1 arcmin) Pointing Stability: 5×10^{-6} rad (1 arcsec) Max Slew Rate: 2.9×10^{-3} rad/sec (540 arcsec/sec) Min Slew Rate: 5×10^{-6} rad/sec (1 arcsec/sec) Pointing Hold Time: 6000 secs*	Desired Incl: 0° Acceptable Incl: 55° to > 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	Telescope Axes Parallel to 5×10^{-6} rad (1 arcsec)
1.4.2 Large Area Moderate Resolution X-ray Telescope Experiments	2546 (5612)	21 (746)	1.02D x 13.7L (3.35D x 45L) (Retractable to 30 ft length for transportation)	Average: 220.9 Peak: 223.9 Standby: 190 Total: 2090 watt-hours	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Observational Astronomers	Temp Limits: 272 to 274°K Ops Atmosphere: 1.33×10^{-4} N/m^2 (< 10^{-6} Torr) Gravity Level: < 10^{-3} g, ops Radiation Sensitivity: 1 mrad/hr	Setup: 8.5 Ops Cycle: 1.6 to 9.5 Maintenance: 7.5	Picture Elements Per Image: 1,048,576 Images/Sec: 1 Digital Picture Data: 7.34×10^6 bps/image Internally Processed Non Imaging Data: Command 20 bps Science/Exps: 5.36×10^3 bps Housekeeping: 53 bps	Pointing Accuracy: 2.9×10^{-4} rad (60 arcsec) Pointing Stability: 5×10^{-6} rad (1 arcsec) Max Slew Rate: 2.9×10^{-3} rad/sec (540 arcsec/sec Min Slew Rate: 5×10^{-6} rad/sec (1 arcsec/sec) Pointing Hold Time: 6000 secs*	Desired Incl: 0° Acceptable Incl: 55° to 70° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	Telescope Axes Parallel to 5×10^{-6} rad (1 arcsec)
1.4.3 Large Proportional Counter Array Experiment	89 (196)	0.275 (9.66)	1.01 x 6.35 x 3.9 (3.33 x 2.08 x 1.25)	Average: 29.3 Peak: 29.3 Standby: — Total: 278.4 watt-hours	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Observational Astronomers	Temp Limits: 272 to 274°K Ops Atmosphere: 1.33×10^{-4} N/m^2 (< 10^{-6} Torr) Gravity Level: — Radiation Sensitivity: 1 mrad/hr	Setup: 2 Ops Cycle: 0.1 Maintenance: 2	Picture Elements Per Image: — Images/Sec: — Digital Picture Data: — Non Imaging Data: Command Science/Exps: 2.21×10^3 bps Housekeeping: —	Pointing Accuracy: 1.7×10^{-3} rad (0.1°) Pointing Stability: Per X-ray Telescope Max Slew Rate: 2.9×10^{-3} rad/sec (540 arcsec/sec) Min Slew Rate: — Pointing Hold Time: 60000 secs*	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	

*Mission may be subdivided into 100 minute (6000 sec) segments; for weak sources observation may extend to about 400 min.

Table 1-7. X-Ray Stellar Astronomy Experiment Requirements Summary (Continued)

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.4 Scintillation Counting Experiment	144 (318)	0.226 (8)	0.56 x 0.51 x 0.76 (1.83 x 1.66 x 2.5)	Average: 10.8 Peak: 10.8 Standby: — Total: 102.6 watt-hours	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Observational Astronomers	Temp Limits: 272 to 274°K Ops Atmosphere: 1.33×10^{-4} N/m^2 $< 10^{-6}$ Torr Gravity Level: — Radiation Sensitivity: 1 mrad/hr	Setup: 2 Ops Cycle: 1 Maintenance: 2	Picture Elements Per Image: — Images/Sec: — Digital Picture Data: — Non-Imaging Data: Command Science/Exps: 830 bps Housekeeping: —	Pointing Accuracy: 1.7×10^{-3} rad (0.1°) Pointing Stability: Per X-ray Telescope Max Slew Rate: 2.6×10^{-3} rad/sec (540 arcsec/sec) Min Slew Rate: 5×10^6 rad/sec (< 1 arcsec/sec) Pointing Hold Time: 6000 sec*	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	
1.4.5 500 cm^2 Crystal Spectrograph Experiments	62 (137)	0.583 (20.3)	0.51 x 0.73 x 1.5 (1.66 x 2.4 x 5)	Average: 12 Peak: 12 Standby: — Total: 113 watt-hours	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Spectroscopist Scientist/ Astronomer	Temp Limits: 272 to 274°K Ops Atmosphere: 1.33×10^{-4} N/m^2 $< 10^{-6}$ Torr Gravity Level: — Radiation Sensitivity: 1 mrad/hr	Setup: 2 Ops Cycle: 0.22 to 1.66 Maintenance 2	Picture Elements Per Image: Images/Sec: — Digital Picture Data: — Non-Imaging Data: Command Science/Exps: 3627 bps Housekeeping: —	Pointing Accuracy: 1.7×10^{-3} rad (0.1°) Pointing Stability: Per X-ray Telescope Max Slew Rate: 2.6×10^{-3} rad/sec (540 arcsec/sec) Min Slew Rate: 5×10^6 rad/sec (< 1 arcsec/sec) Pointing Hold Time: 6000 sec*	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	
1.4.6 Transient X-ray Phenomena Detection	181 (400)	0.2 (7.2)	4 pkg, each 1/2 x 0.46^3 1/2 x (1.5^3)	Average: (36) Peak: (36) Standby: — Total: 342	Space Crew: Scientist/ Astronaut Ground-Based Ops Control Crew: Observational Astronomer	Temp Limits: 272 to 274°K Ops Atmosphere: 0-10^5 N/m^2, 1.33×10^{-4} N/m^2 (0-15 psi, 10^{-6} Torr)	Setup: 2 Ops Cycle: 0.1 Maintenance: 2	Picture Elements Per Image: — Images/Sec: — Digital Picture Data: — Non-Imaging Data: — Science/Exps: — Housekeeping: —	Pointing Accuracy: 1.7×10^{-3} rad (0.1°) Pointing Stability: Per X-ray Telescope Max Slew Rate: 2.6×10^{-3} rad/sec (540 arcsec/sec) Min Slew Rate: 5×10^6 rad/sec (< 1 arcsec/sec) Pointing Hold Time: 6000 sec*	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (200 to 400 n.mi.)	Mounted Around Periphery of Exp Carrier Vehicle, Avoid Obscuration

*Mission may be subdivided into 100 minute (6000 sec) segments; for weak sources observation may extend to about 400 min.

sources with reasonable (100 minute) observing times. Objectives of the high resolution X-ray stellar astronomy observations/measurements are as follows:

a. Location of moderate-strength X-ray sources with angular stability to 5×10^{-6} rad (1 arcsec) and an angular accuracy better than 2.9×10^{-4} rad (1 arcmin) (preferably 5×10^{-6} rad).

b. Measurement of angular size, shape and density of regions of X-ray emission sources.

c. Spectral measurements with resolutions between 0.1 and 0.01 percent.

d. Correlation of X-ray emissions from sources with activity in the visible, UV, and RF portions of the spectrum.

The experiments begin with aspect sensing and correlated high resolution imaging to enable source location, identification, and image stabilization. Then higher resolution spectrometer measurements are made.

1.4.1.2 Description

a. Aspect Sensing. Although used for support, aspect sensing contributes to the high resolution imagery experiment (1.4.1.2 b). The primary function of aspect sensing is to record the history of the telescope pointing; it may provide other functions such as providing error signals for stabilization purposes or even, as an experiment, to observe ultraviolet emission from selected stars.

The requirement for aspect is most intimate to the high resolution imaging experiment which is attempting to record position of X-ray sources to 5×10^{-6} rad (1 arcsec). In order to do so it is necessary to record individual stellar positions continuously with a precision of about 5×10^{-5} rad (10 arcsec). The proposed aspect sensing equipment consists of a long focal length lens or mirror and a high sensitivity visible-light image tube. Given an image tube with 1000 line resolution, a field of view of 3.05×10^{-4} rad^2 (7.5 square degrees) results. To obtain an average of five stars in such a field, the device must be sensitive to 8th-magnitude stars, which is quite feasible for a system with a 152 mm (6 in.) diameter lens and a one second integration time.

The aspect lens is mechanically an integral part of the high resolution X-ray mirror, and the aspect readout system is supported by the same frame which supports the high resolution telescope, as previously discussed. A sun sensor controlling a sun shade prevents overdriving the image intensifier/SEC transducer.

The star field data will be accumulated, and the data telemetered at a rate of one frame/second. The vidicon will be scanned using a 1024 by 1024 element raster requiring an individual element sweep rate of somewhat greater than one element

per μ sec. Figure 1-13 is a block diagram of the electronic system. A pseudo-automatic threshold control will limit the number of telemetered data points to about 10 of the brightest stars in the frame. The automatic threshold system counts the number of stars which exceed a baseline amplitude threshold. If the number exceeds the maximum upper limit, the thresholds of the discriminator are raised by a proportionate value. If the number is less than the minimum acceptable limit, the thresholds of the discriminator are lowered. The dead band provided by the upper and lower set points will minimize system hunting. Provisions for establishing upper and lower set point thresholds via command links are included. The adjacent element inhibit excludes the scattered light near bright stars and extended objects from the automatic threshold system. The video data is processed prior to being digitized. An event marker permits the star amplitude to be digitized and stored in the buffer memory along with its X and Y address.

It may be necessary to use a second coarser aspect system to provide intermediate precision aspect data. Such a system can be similar to the high precision system except for the use of a shorter focal length lens and a larger field of view.

Aspect sensing is, of course, related to the supporting-vehicle pointing accuracy and stabilization. Where the supporting vehicle stabilization is controlled by offset guide star trackers to better than 5×10^{-6} rad (1 arcsec), as desired, the aspect sensing equipment becomes primarily a means for correlating X-ray information and visible/UV light information with the X-ray data. For high resolution spectrometry, the X-ray telescope needs high angular stability.

b. High Resolution Imaging and Low Resolution Spectrometry. The experiment is designed to obtain high resolution images of X-ray sources from which accurate position, spatial structure, intensity, and temporal variation measurements may be made. Low resolution spectral measurements will also be performed. A block diagram of the experiment is given in Figure 1-14.

The high resolution images are obtained by focusing the X-rays upon an X-ray sensitive multichannel plate image intensifier and recording the resulting visual image with a secondary emission current or other type of video tube. The present design provides four interchangeable image intensifiers for increased reliability and to allow the use of X-ray photocathodes with different spectral responses.

Low resolution spectral data are obtained by dispersing incident X-rays with a transmission grating located near the telescope mirror. Each point source in the field of view thus results in a point image and a line image in which the position along the line follows the normal grating function of wavelength. The

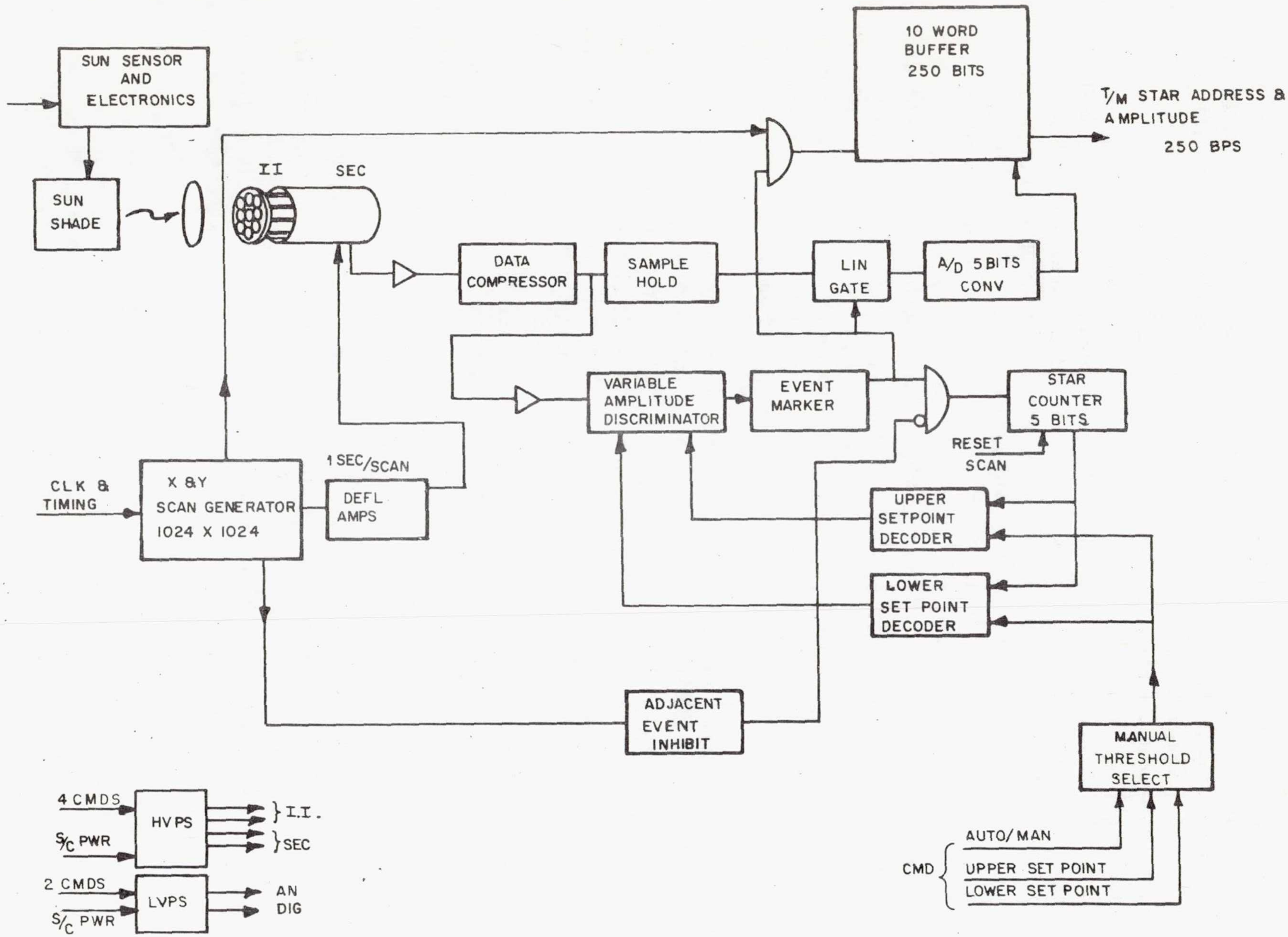


Figure 1-13. Aspect Sensing

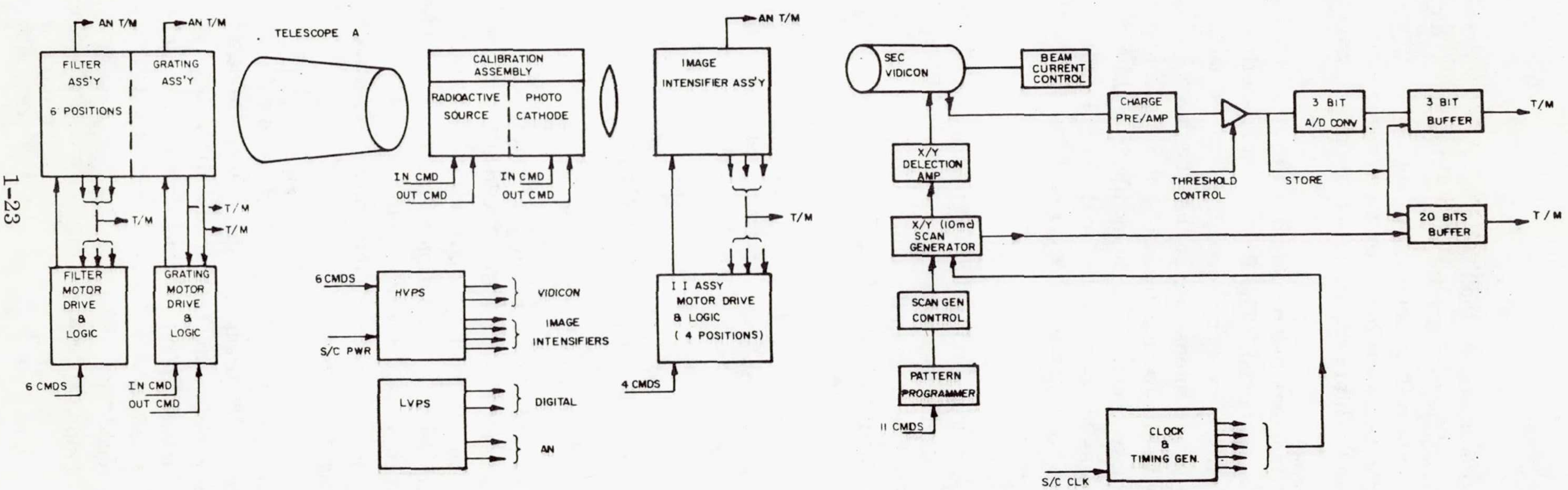


Figure 1-14. Block Diagram, High Resolution Imaging Experiment

spectral resolution is poorer than obtained with the crystal spectrometers to be discussed later, but as data are taken simultaneously over the entire spectral range, a higher data rate is obtained which enables investigation of weaker sources and of the temporal behavior of stronger sources. A six-position filter wheel is included to obtain cruder spectral data from even weaker sources.

The experiment includes two principal calibration devices which may be inserted or removed upon command. The first, a radio-active source, allows a calibration of the detector efficiency. The second, a light-sensitive photocathode, may be placed near the image intensifier so that the detector will become sensitive to visual stars for in-flight measurements of the alignment offset between the telescope and aspect systems. The photocathode will be deposited upon a glass slide of proper thickness to compensate for the small distance between the photocathode and the telescope focal plane. Fiducial marks may be obtained by focusing small electron or UV sources onto the image intensifier.

The SEC vidicon image field is divided into 1024 by 1024 (5×10^{-6} rad or 1 arcsec) elements which results in a total field of view of 5×10^{-3} rad (17 arcmin). It is not presently feasible to scan the entire field and maintain the one millisecond time resolution required for fast pulsar measurements; tentatively, four scanning modes have been selected:

Mode	Field Size	Scan Rate (Hz)
A	1024 × 1024	16
B	128 × 128	1024
C	256 × 256	256
D	256 × 1024	64

All of these scan modes require approximately a 17 MHz element scan rate. Mode A provides a scan of the entire field. Mode B provides the desired millisecond time accuracy for a field of approximately 5.8×10^{-4} rad (2 arcmin). Mode C provides acceptable time resolution with a larger field of view and is included to allow a somewhat relaxed absolute pointing requirement. Mode D is included to obtain better time resolution during grating exposures; the long axis is oriented along the grating dispersion.

The combination of high resolution, high scan rate and variable field of view imposes severe restrictions upon the scanning electronics. A combination of digital and analog deflection techniques will be used to provide a reversing linear deflection for the high speed horizontal deflection and a nonreversing digital deflection with blanked flyback for the lower speed virtical deflection. This approach minimizes the "dead time" associated with digital deflection rise times and yet maintains the flexibility required for variable field scanning.

At the beginning of each scan, a frame identification code and time will be stored and for each scan element in which the charge exceeds a preset threshold, twenty address bits and three amplitude bits will be stored. A maximum of 1,000 events/second is expected, and therefore the data requirement will be approximately 25,000 bits/second, including some housekeeping and the frame identification codes. The proposed data technique requires fewer bits than reading out the entire image of about 10^6 resolution elements, and it is unlikely that data compression techniques exist which substantially reduce the data rate since most of the events are detector background and occur randomly over the field of view. There are indications that the detector noise rate may be less than stated here, but this cannot be assumed at the present time. The only source which will contribute a comparable number of events is Sco X-1, which can be observed with a smaller field of view and correspondingly smaller noise rate. The modes with smaller fields of view will require fewer address bits/event but more frame identifications will be necessary.

Power, mass, data transmission and command requirements are summarized in Section 1.4.1.4.

c. High Resolution X-Ray Spectroscopy. A high resolution X-ray crystal spectrometer is used to measure the spectrum of a moderate-strength source from 2×10^{-9} to 10^{-9} m (20 Å to 10 Å or 0.62 keV to 1.24 keV) with a 0 to 10^{-10} m (0 to 1 Å) or better resolution. Crystals will reflect X-rays efficiently only when the incident angle is within a small angular interval about the Bragg angle defined by $n \lambda = 2d \sin \theta_n$. The instrument utilizes the spectral selectivity to form a high resolution spectrometer. The geometry of the device conforms to conventional Johann geometry (Figure 1-15) in which a cylindrical crystal of radius 2R is tangent to the focusing circle of radius R. The focal plane image of a source is on the focusing circle, so all rays strike the crystal near the same angle, and therefore only a narrow range of wavelengths is reflected. All reflected rays are focused to a line on the focusing circle at the same distance from the crystal tangency point as the source, and conventionally a small detector is placed at this location. The fact that the angle of incidence is a (slow) function of the crystal location where the ray is reflected results in some loss of resolution when a single detector on the focal circle is used. This loss of information is avoided in the instrument by placing an array of detectors near the crystal so that a reflected ray can be associated with a specific portion of the crystal and therefore with smaller intervals of incident angle and wavelength.

Normally, the instrument will be used to scan a portion of the spectrum; this is accomplished by simultaneously rotating the crystal, rotating the detector about the crystal through twice the angle of the crystal rotation, and translating the crystal along the telescope axis. The instrument will scan back and forth between limits that can be set by commands; these limits may be narrow for studying

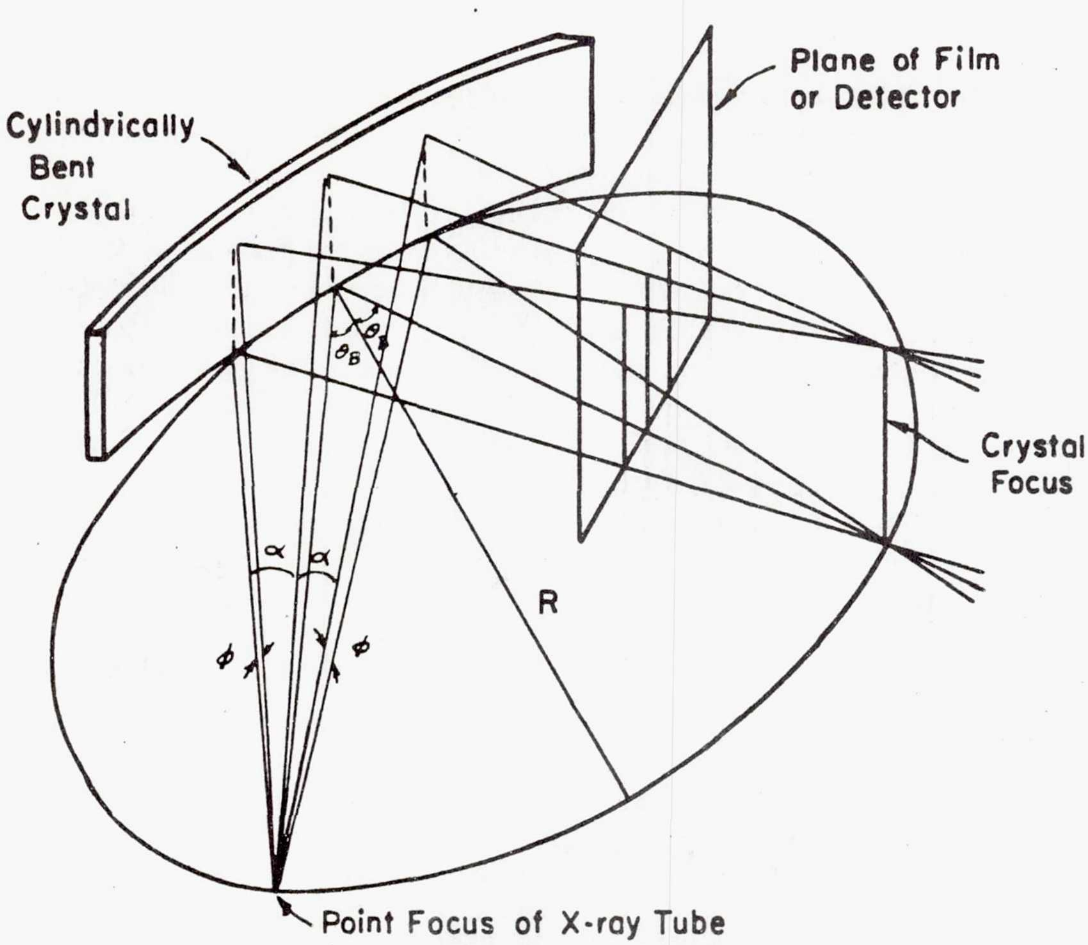


Figure 1-15. Focusing Circle Geometry

an emission line, or broad for investigating an entire spectrum. Four slewing rates will be required and up to six crystals will be available for different portions of the spectrum. However, the spectral line detector (for each crystal), with the total incident flux spread out along a circle, sees a much reduced signal and as a consequence requires a much longer integration time to produce an adequate spectrum. In general, integration times will be in the 10 to 40 minute range, depending on spectral resolution and source intensity, and may extend to 100 minutes on weak sources. More than one orbital pass will be required to obtain a high-resolution spectrum ($\lambda/\Delta\lambda$ equals 100 on a source such as 10^{-4} of Sco X-1 intensity).

1.4.1.3 High Resolution X-Ray Observation/Measurement Program. After the X-ray telescope and its associated instruments have been checked at a space station or by a shuttle service vehicle, a repetitive preparation/observation cycle will be initiated. Time on a source will depend on its strength, location, and the extent to which the earth obscures it. In general, long-duration observations would be programmed for that time of the year when the X-ray telescope support vehicle orbit plane is roughly perpendicular to the direction of the source. The operations cycle for typical expected X-ray sources is as follows:

a. Preparation (At observing station location; controlled remotely from space station or ground control mount.)

		Time, Minutes
1.	Observation direction selection	5
2.	Remotely controlled equipment checkout (at 6 min/instr)	36
3.	Offset reference guide star selection (may be several sets in sequence as visible from orbit)	5
4.	Preorientation (slewing to guide star direction)	9

b. Observation Cycle (Up to 204.5 minutes)

		Time, Minutes
1.	Actual guide stars (2) acquisition	0.5
2.	Detailed location of selected observation area	0.5
3.	Focus and lock-on to selected source (may be via direction hold of guidance)	0.5
4.	Observation and measurement program	
	a) Aspect sensing and high resolution imaging	Up to 100
	b) Experiment interchange and refocus	3
	c) High resolution spectrometry	Up to 100
	d) Repeat cycle as necessary	

1.4.1.4 Interface, Support and Performance Requirements. Table 1-8 shows interface, support, and performance requirements for the high resolution X-ray experiments. Please note that a large amount of picture data would need transmission to ground if built-in data processing and selection techniques were not provided in the experiment equipment.

1.4.1.5 Potential Role of Man. Man provides periodic servicing, maintenance, and adjustment of the high resolution telescope experiments in space as well as remote control and monitoring of astronomy operations. Control may be from crew in the space station or from the ground where an appropriate team of observational astronomers are expected to aid in the X-ray telescope experiment operations.

1.4.1.6 Available Background Data

a. ASE-2266A Preliminary Study: Telescope and Scientific Subsystem for a High Energy Astronomy Observation, 1 August 1969, rev. 26 September 1969, Contract NAS 8-24668, SR & T Task No. 611-188-41-01-12-51 + NSR 22-009-321.

Table 1-8. High Resolution X-Ray Telescope Experiment Interface, Support and Performance Requirements

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	a. Aspect Sensing	b. High Resolution Imaging/Low Res Spectrometry	c. High Resolution X-ray Spectroscopy						ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	Aspect Optics Aspect Detector X-ray Telescope Structure	Aspect Optics Aspect Detector X-ray Telescope X-ray Imaging Detector Transmission Grating Filter Wheel Heaters	X-ray Telescope Crystal Spectrometer Heaters						a + b, c sequentially	a + b + c
Launch Mass, kg (Weight, lb)	63.5 (140)	63.5 + 1025 + 59 + 14 + 14 (140 + 2260 + 130 + 30 + 30)	1025 + 43.5 (2260 + 96)						1218 (2686)	1218 (2686)
Logistics Support										
Consumables, kg/180D (lb/180D)										
Spares, kg/180D (lb/180D)		Spares incorporated in updated instruments*								
Crew Support										
Initial Setup, Manhours/180D	0.5	1.0	1.0						2.5	2.5
Periodic Serv. & Maint., Manhours/180D	0.5	1.0	1.0						2.5	2.5
Operation, Remote Control, Manhours/Observation Cycle	Up to 1.66 in parallel with b	Up to 1.66	Up to 1.66						Up to 3.4	Up to 3.4
Electric Power:										
Peak Load, Watts	21.06	150 + 40.3	150 + 42.7						193	254
Average Load, Watts	18.36	100 + 21.3	100 + 32.4						132.4	172
Standby Load, Watts	18.36	21.3	32.4						32.4	72.06
Environmental Control										
Desired Vehicle Heat Sink Temp, °K	273 ± 10°	273 ± 10°	273 ± 10°						273 ± 10°	273 ± 10
Temp. Limits, Stowed, °K	253 to 309	253 to 309	253 to 309						253 to 309	253 to 309
Temp. Range, Ops., °K	286 to 300	290 to 294	290 to 294						290 to 294	290 to 294
Max. Temp. Difference, °K	2	2	2						2	2
Relative Humidity, %	< 40	< 40	< 40						< 40	< 40
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 0 to 15	1.33×10^{-4} $< 10^{-6}$ Torr, ops	1.33×10^{-4} $< 10^{-6}$ Torr, ops						1.33×10^{-4} $< 10^{-6}$ Torr	1.33×10^{-4} $< 10^{-6}$ Torr
Cleanliness Class	100,000	10,000	10,000						10,000	
Gravity Level, Max. g	$< 10^{-3}$, operating	$< 10^{-4}$, on source	$< 10^{-4}$, on source						$< 10^{-3}$	$< 10^{-4}$
Radiation Sensitivity, millirad/hr	< 1	< 1	≤ 1						≤ 1	≤ 1
Contamination Sensitivity	Moderate	Moderate	Moderate						Moderate	Moderate

*See Special Requirements.

Table 1-8. High Resolution X-Ray Telescope Experiment Interface, Support and Performance Requirements (Contd)

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	a. Aspect Sensing	b. High Resolution Imaging/Low Res Spectrometry	c. High Resolution X-ray Spectroscopy	ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:					
Desired Inclination, deg	0	0	0	0	0
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	
Desired Altitude, km	740 to 930	740 to 930	740 to 930		740 to 930
(n.mi.)	(400 to 500)	(400 to 500)	(400 to 500)		(400 to 500)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	
Orientation:					
Observed Object Location	via reference stars	via reference stars	via reference stars	via reference stars	via reference stars
Observed Object Brightness, mag., m_v	8	varies	varies	varies	varies
Observation Field of View	4.8×10^{-2} rad (2.742°)	11.6×10^{-4} rad (4 arcmin)	11.6×10^{-4} rad (4 arcmin)		11.6×10^{-4} rad (4 arcmin)
Pointing Accuracy, rad	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
(arcsec)	(≤60)	(≤60)	(≤60)	(≤60)	(≤60)
Pointing Stability, rad/obs time	$<5 \times 10^{-6}$	$<5 \times 10^{-6}$	19×10^{-6}	5×10^{-6}	5×10^{-6}
(arcsec/obs time)	(≤1)	(≤1)	(≤4)	(1)	(1)
Slew Rate, max., rad/sec	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}
(arcsec/sec)	(≤540)	(≤540)	(≤540)	(≤540)	(≤540)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
(arcsec/sec)	(<1)	(<1)	(<1)	(< 1)	(<1)
Pointing Hold Time, sec	Up to 6000	Up to 6000	Up to 6000	Up to 6000	Up to 6000
Data Requirements/Observation Cycle:					
Spectral Range	8×10^{-7} to 3×10^{-7} m (8000 Å to 3000 Å)	1×10^{-8} to 2×10^{-10} m (100 Å to 2 Å) (0.124 to 6.2 keV)	2×10^{-9} to 10^{-9} m (20 Å to 10 Å) (0.62 to 1.24 keV)	—	—
Imaging Data					
Desired Resolution, (spatial or spectral)	Selectable: 5×10^{-6} rad (1 arcsec); 3.6×10^{-5} rad (7.46 arcsec)	5×10^{-6} rad (1 arcsec)	5×10^{-7} m (0.1 Å) (from 10 Å to 20 Å)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad, 5×10^{-7} m (1 arcsec, 0.1 Å)
Equiv. Image Format Size, mm	24 × 24	24 × 24	—	24 × 24	24 × 24
Picture Elements/Image	1,048,576	1,048,576*	—	1,048,576	1,048,576
Images/Data Set					
Images/Second	1	16*, 64, 256, 1024	—	—	(16, 64, 256, 1024)
Photometric Resolution, %, bits	1, 7	1, 7		—	1, 7
Equiv. Analog Data, MHz	(~.11 optional)	(1.7×10^2)	—	—	11 optional
Equiv. Digital Data, bits/image	(7.343×10^6)	(1.19×10^8)		1.19×10^2	1.19×10^2
Non-Imaging Data: Command Data, bps	6	32	40	40	40
Science/Exp. Data, bps	250	2.5×10^4	1.1×10^4	2.5×10^4	2.5×10^4
Housekeeping Data, bps	15	200	(~200)	415	415
Special Requirements:					
Updating Cycle, Years	2	2	2	2	2
Mass, kg/yr (Weight, lb/yr)	5.7 (12.5)	16 (35)	40 (96)	65 (143.5)	65 (143.5)
Volume, m^3/yr (ft^3/yr)	2.83×10^{-2} (1)	5.7×10^{-2} (2)	1.9×10^{-1} (6.6)	2.72×10^{-1} (9.6)	2.72×10^{-1} (9.6)

*Only for 1024 × 1024 image at 16 frames per second; other matrices scanned are 256 × 10±4 at 64 frames/sec, 256 ×±56 frames/sec, and 128 × 128 at 1024 frames/sec.

b. NASA SP-213, A Long Range Program in Space Astronomy.

c. Minutes of Astronomy Review Group Meeting at MSFC on 28 July, 1970.

1.4.2 LARGE-AREA MODERATE-RESOLUTION X-RAY TELESCOPE EXPERIMENTS. Large-area moderate-resolution X-ray telescope experiments include: Maximum sensitivity detection, position-sensitive proportional counter imaging, mosaic spectrometry, and polarimetry.

1.4.2.1 Scientific or Technical Objectives. Scientific or technical objectives of the large area X-ray telescope experiments are:

a. High sensitivity surveys to establish catalogs of X-ray sources containing information on position intensity and spectral distribution;

b. Detection of sources that are 10^{-6} of Sco X-1 in intensity;

c. Observations of regions of large source density to a resolution better than 2.9×10^{-4} rad (1 arcmin), particularly in regions of low galactic latitude;

d. Correlated determination of locations for a large number of sources with precisions between 5×10^{-6} rad (1 arcsec) and 2.9×10^{-4} rad (1 arcmin);

e. Observations over a broad wavelength range to exhibit spectral differences between sources in terms of hardness and degree of attenuation to give direct information on nature of X-ray sources;

f. True diffuse-sky X-ray background which gets focused by the telescope; and

g. "Internal" detector background due to charged particles and Compton interactions of higher energy photons in the crystal.

1.4.2.2 Description.

a. Maximum Sensitivity Detection. Solid state detectors have the best presently obtainable detector spectral resolution and efficiency using direct photoelectric interactions. The solid state detector experiment is primarily designed for realizing the full sensitivity capability of a grazing incidence X-ray telescope and providing spectroscopy with resolution sufficient for measuring line intensities. The experiment utilizes a cooled Si(Li) detector with an X-ray-transparent front window to extend the high efficiency to soft X-rays ($\sim 10^{-9}$ m, 1.25 keV, or 10 Å). The principal detector is surrounded by anticoincidence solid state detectors to minimize the background arising from charged particles and Compton scattered photons.

The present state-of-the-art Si(Li) technology allows the achievement of an energy resolution of 125 eV FWHM (noise-limited, almost independent of energy). This will not improve very much in the next few years, since at 3 eV/ion-pair the

system resolution is converging on that resolution allowed by electron statistics. The present technology also allows for entrance windows of $< 0.1\ \mu$m of dead silicon, which would be virtually transparent to celestial X-rays were it not for the 40 μg/cm^2 of gold used for the creation of the p-contact. This amount of gold reduces the transparency of the window to only ~20% at 16 fJ (1 keV or 12.4 Å), but a like amount of nickel substituted for the gold, for example, could be used interchangeably with the gold (electrically), and would make the window considerably more transparent.

To get an estimate of operation with background interference, consider a bare crystal (no anticoincidence) of area = 1 cm^2 and depth = 1 mm, and distinguish between two separate background regimes:

$$L \approx 6 \text{ meters (20 ft)} \qquad \frac{dI}{dE} \approx \frac{20}{E^2} \text{ cm}^{-2} \text{ sec}^{-1} \text{ sr}^{-1} \text{ keV}^{-1}$$

We get N = 7 counts in 10^3 sec in the energy range 0.5-5 keV. This number is just proportional to the area of the detector, and can be made smaller if this area is made smaller. We note, however, that the diffuse background contamination of a 100% efficient device in the focal plane of the above telescope is only about 3×10^{-4} cts/arcmin^2-sec. In the absence of any other background contamination, then, with the restriction of a 10^3 sec exposure, a detector need not be smaller than 3 arcmin^2 (3 mm diameter) to have an average background rate of one count per total exposure.

With regard to charged particle rejection, it is obvious that active anticoincidence is required for extremely low background. Almost all charged particles which pass through the device will identify themselves by the deposition of more than a few keV of energy, but the very few which cut the corners of the crystal must be anticoincidence if we desire maximum detector sensitivity to weak sources.

A meaningful estimate of background contamination from Compton interactions in the raw device described above can easily be made because we know the geometry so well (i.e., we know the location and extent of the dead material). The contribution from this source has been estimated on the basis of no collimation or attenuation of the diffuse background above 10 keV (clearly much worse than the actual case). The total contribution is best broken down into three energy ranges for the incident Compton scattered photons, and for an exposure of 10^3 sec with the above raw 1 cm^2 detector we obtain:

$$N\ (E < 0.8 \text{ nJ, 50 keV, or } 0.25 \text{ Å}) = 5.8 \text{ cts}/10^3 \text{ sec}$$

$$N\ (50 < E < 1.6 \text{ nJ, 100 keV, or } 0.12 \text{ Å}) = 1.9 \text{ cts}/10^3 \text{ sec}$$

$$N\ (E > 1.6 \text{ nJ, 100 keV, or } 0.12 \text{ Å}) = 0.07 \text{ cts}/10^3 \text{ sec}$$

We see, immediately, that the detector volume is such that photons with energy > 1.6 nJ (100 keV) will not be a problem, but that lower energy photons will create an 8 fJ to 80 fJ (0.5 to 5 keV) background which is equal to the true 8 to 80 fJ sky background through the telescope. It is only necessary, therefore, to have an efficient (for E < 1.6 nJ or 100 keV) thin dead layer anticoincidence detector to eliminate this component with respect to the 8 to 80 fJ sky background through the telescope. We could use a scintillator like CsI, for example, but we would then have the serious problem of enclosing the dead cold-finger contact to the Si(Li) within the anticoincidence volume. It is much more reasonable to contain the anticoincidence within the cold contact. It is possible to segment the device, as shown in Figure 1-16, taking separate outputs from the A and B portions of the central crystal. The anticoincidence volumes C and D are tentatively chosen to be Ge(Li), since 1 cm of Ge(Li) is a virtual backstop for E < 1.6 nJ (while the same thickness of Si(Li) is still transparent). The detector is then operated in the mode ABCD, with a background for discrete sources limited by the sky background focused by the telescope of 3×10^{-4} cts/sec-arcmin^2. This corresponds to a sensitivity to discrete X-ray sources of about 10^{-4} photons/cm^2-sec in a 10^3 second exposure.

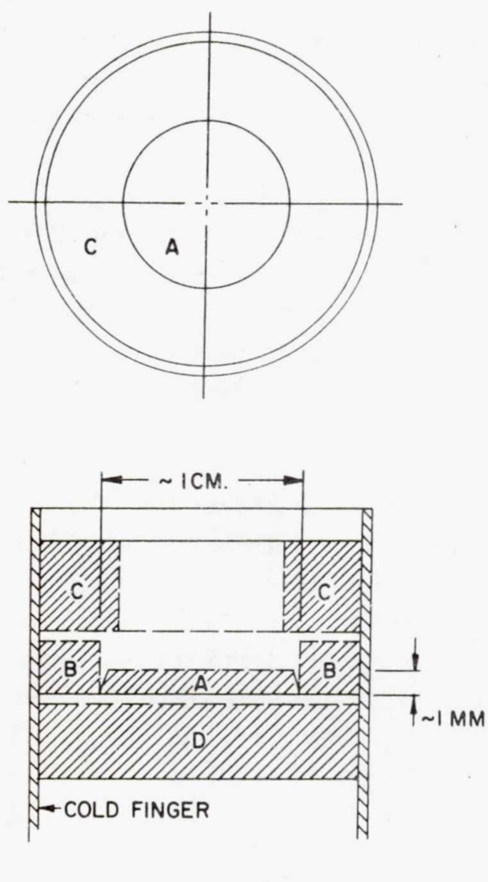


Figure 1-16. Composite Si(Li) Detector

A unique system for correlating the X-ray source with optical images has been devised to complement the X-ray observations. The front surface of the solid-state detector reflects visible light while transmitting the X-ray photons to the sensitive portion of the detector. The visible light reflected from the solid state detector is then imaged by a mirror and lens system and detected.

As shown in Figure 1-17, the Si(Li) detector is placed below the focal plane. Just above this plane, at a 0.875 rad (50 deg) inclination, there is a flat mirror whose central region is appropriately cut out to serve as an entrance port for the incident light cone. Images of X-ray and/or optical sources are formed in the focal plane. Beyond this focal plane, the diverging light rays are reflected by the polished surface of the Si(Li) detector and subsequently by the inclined mirror. They are finally focused by a lens onto a sensitive image detector such as a channel plate multiplier.

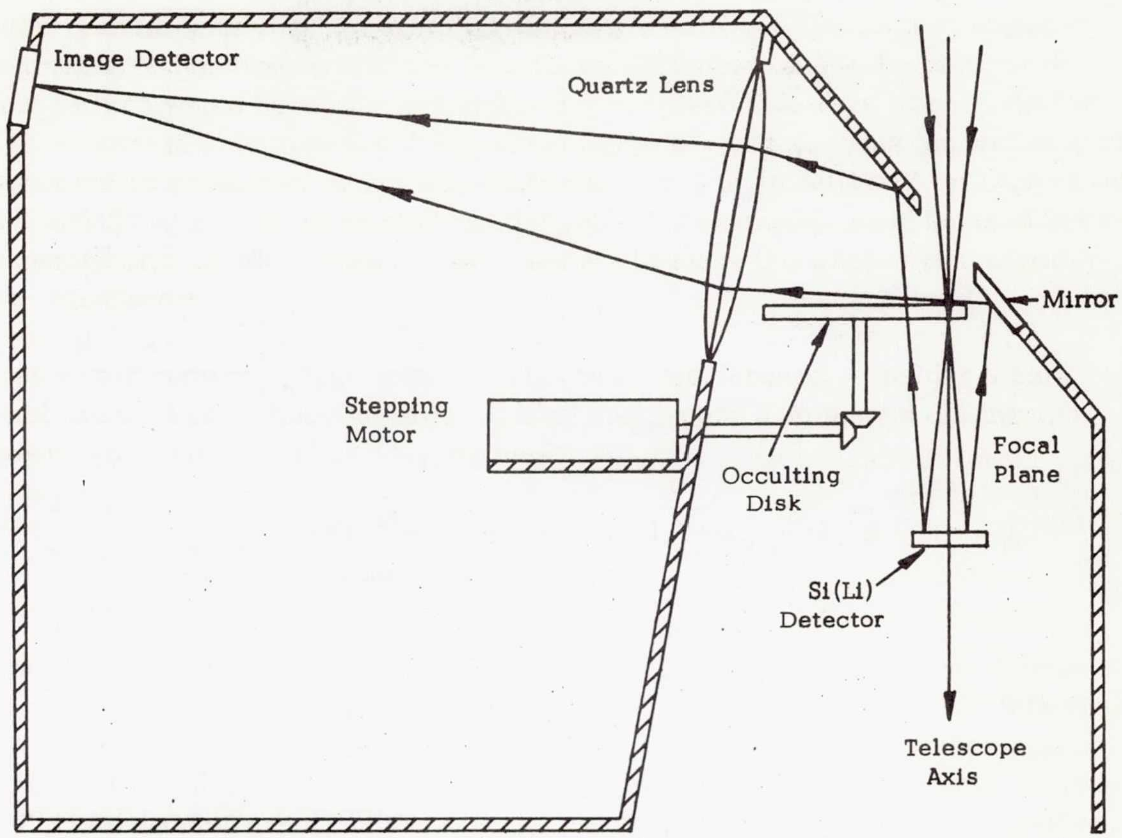


Figure 1-17. Optical Correlator (Symbolic)

The location of an X-ray source and the correlation with optical data is accomplished by means of beam choppers (wires) located in the focal plane and sequentially scanning the field of view in a stepwise motion. The limiting resolution of better than 5×10^{-5} rad (10 arcsec) expected for the telescope, and an anticipated jitter of about 5×10^{-6} rad/sec (1 arcsec/sec), allow the efficient use of 5×10^{-5} rad (10 arcsec) resolution elements in a 10 second exposure. We may note, however, that if we locate a point X-ray source to an accuracy 5×10^{-5} rad we will, in most cases, be in a position of identifying it with an optical counterpart of 21st magnitude or brighter. The expected sensitivity of this optical system for direct stellar identification is for 18th magnitude or brighter (for 10 second exposure).

The present plan is to have the beam choppers controlled by a programmable stepping motor so that the dwell times at any position will be about 10 seconds and the steps of each chopper will be matched to its occultation width. In this manner, the total occultation time for a point source will be less than 10% of the overall exposure, in accordance with the pursuit of a maximum sensitivity experiment.

An electronics block diagram is shown in Figure 1-18. In addition to the indicated telemetry, there will be some synchronization and housekeeping telemetry requirements. The total will be far less than with other operational modes of the telescope.

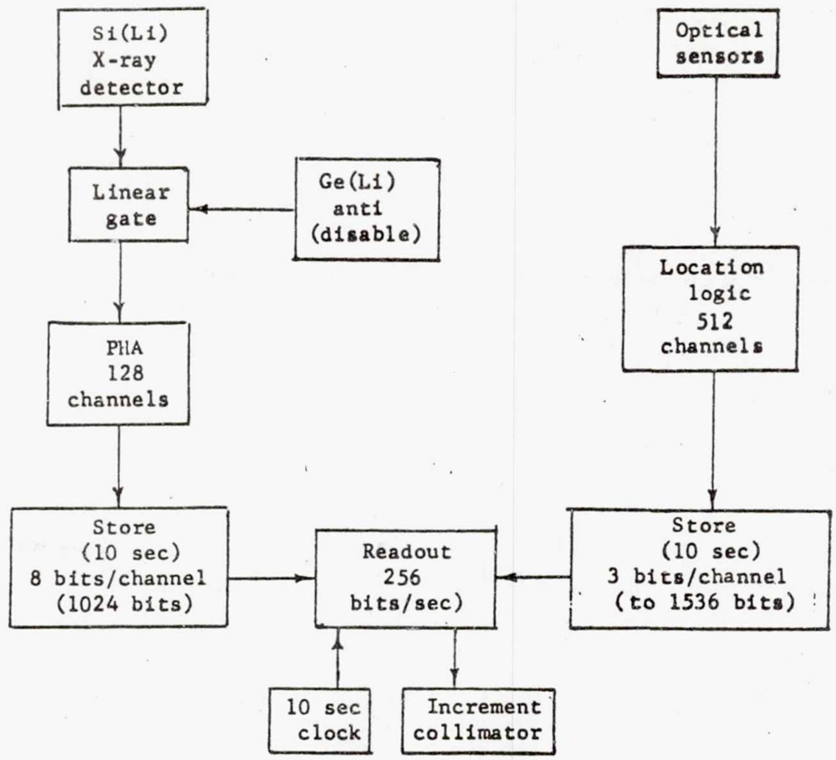


Figure 1-18. Block Diagram for Maximum Sensitivity Detector

Weight and power estimates for this detector are dominated by the refrigeration system which unfortunately cannot be defined well until the vehicle thermal system is understood. Very conservative weight and power estimates have been made until better information becomes available. It is assumed that the refrigerator will be operated for extensive periods when the rest of the experiment is inactive.

b. Position-Sensitive Proportional Counter Imaging. An imaging detector sensitive at low energies has been included for use with the large collector area X-ray telescope for measuring the structure in the diffuse background and the soft coronal emission of nearby typical stars. The detector is a multi-anode proportional counter in which the anodes are constructed of a resistive material such as one mil nichrome (20 ohms/cm). The component along the wire is measured by comparing the charge collected at the two ends by low input impedance, charge-sensitive preamplifiers. The orthogonal component is determined by the anode wire collecting the charge. In the present design there are 32 anode wires spaced at 2.9×10^{-4} rad (1 arcmin) intervals. In an alternative design being considered, the spacing of the center ten channels would be reduced to 9.7×10^{-5} rad (1/3 arcmin) to take advantage of the improved detector resolution in the center of the field of view. To maintain symmetry, each of the outer 22 channels would consist of 3 anodes wired in parallel so that all anodes would have the same spacing and therefore the same electrical characteristics.

A block diagram of the electronics is shown in Figure 1-19. If individual preamplifiers were used at the end of each wire, a total of 64 would be required; the actual design requires only 16; the anodes are divided into two groups of 16, each of which is arranged into a 4 by 4 matrix as follows:

		Left Preamplifier				
		1	2	3	4	
	1	1	2	3	4	
Right	2	5	6	7	8	Anode
Preamplifier	3	9	10	11	12	Number
	4	13	14	15	16	

Thus, for example, an event of the 7th anode will result in charge being collected by the second right and third left preamplifier. If the collected charge exceeds a certain threshold the information may be used to form an event address.

The charges collected by all preamplifiers on the left and right sides are then summed to form the signal QR and QW. The position along the wire is given by:

$$\frac{d}{\ell} = \frac{Q_R}{Q_R + Q_L}$$

where d is the distance from the left edge and 1 is the total length of wire. This division could be performed on the spacecraft and only the result telemetered, but we prefer to telemeter both quantities Q_R and Q_L and perform the division on the ground. The 7-bit digitizing of these quantities will result in one part in 16 maximum position error at the edge and one part in 32 error at the center of the field of view for an event with 1/8 of the total charge range. The positioning error for more energetic events will be less.

Q_L and Q_R are also summed to form the total charge Q. This signal is subjected to pulse shape and anticoincidence discrimination, and, if acceptable, produces an event marker and the total charge signal is processed by an 8-channel pulse height analyzer. The pulse height analyzer has a capacity of 2048 events/channel and is read out once per second. It provides the total counting rate and pulse height distribution in the event of a very high counting rate source. In addition, the position coordinates and a more accurate event time for up to 250 events per second are also telemetered to ground. The event marker associated with the first acceptable pulse in each 4-msec time frame results in the following processes:

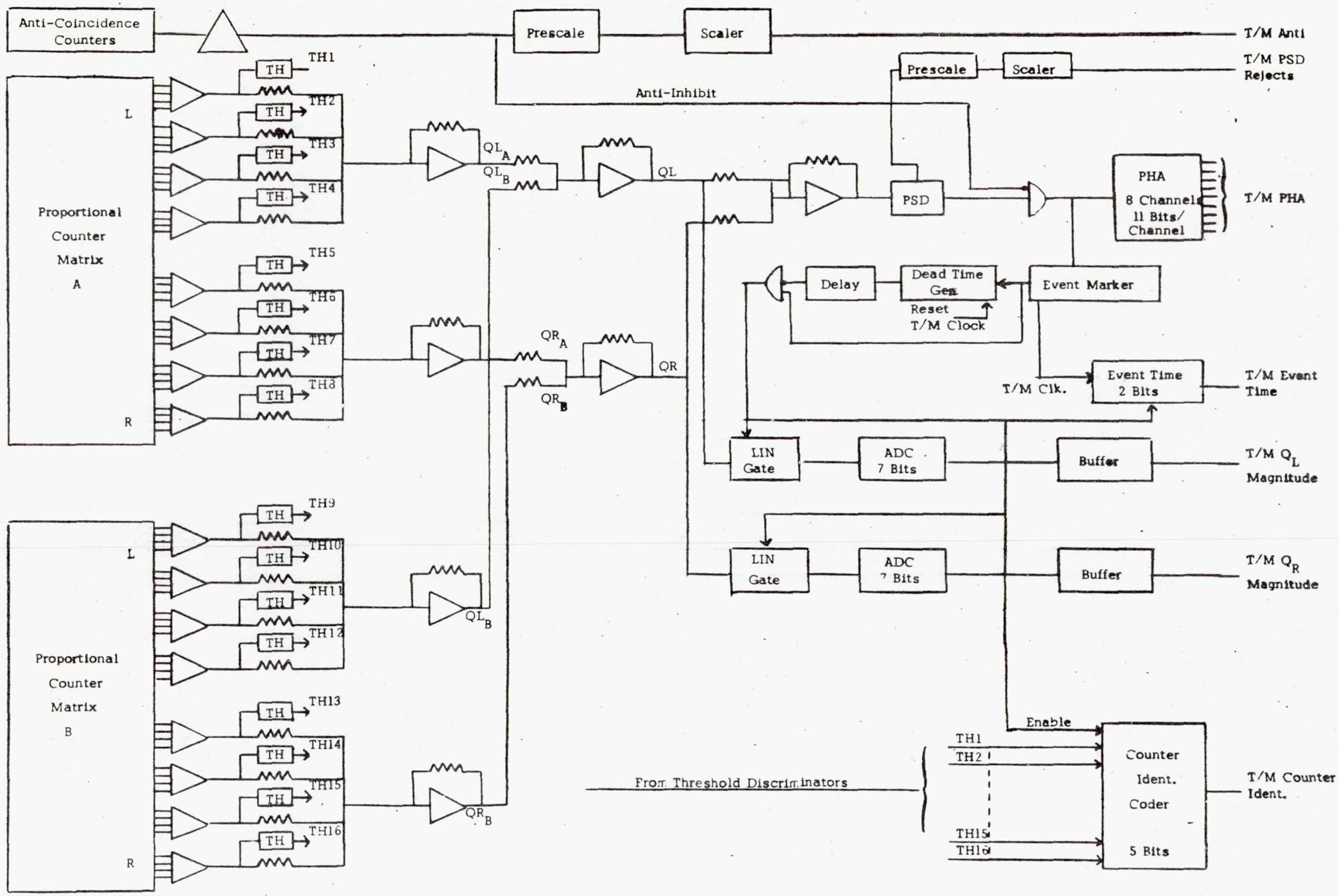


Figure 1-19. Position Sensitive Proportional Counter Imaging

1. Linear Gates present Q_L and Q_R to 7-bit analog-to-digital converters which produce and store in a buffer the 14 event position data bits.

2. The Event Time generator indicates in which 1-msec time window the event occurred within the 4-msec frame (2 bits).

3. The Counter Ident Coder identifies which proportional counter contained the event.

4. A register is set which prevents subsequent events being analyzed during that 4-msec frame.

c. Mosaic Spectrometry. Mosaic crystals and the proportional counter of the previous experiment are used to accomplish mosaic spectrometry. Mosaic crystals, which can be thought of as many thin layers of slightly misaligned perfect crystals, have large effective reflectivities at higher energies. An X-ray photon will penetrate the mosaic crystal with comparatively small absorption until it strikes a subcrystal having the proper Bragg angle; it will then have a high probability of being reflected. The objective crystal spectrometer consists of a crystal placed in front of the large area telescope. Unidirectional X-rays from a point source strike the crystal and are reflected at angles corresponding to their wavelengths. The reflected X-rays are then focused by the large area mirror and detected with the position-sensitive proportional counter. It is not necessary to know the crystal angle with great accuracy since the wavelength is determined by the angle between the incident and reflected ray; it is necessary to know the source and telescope axis directions accurately, and the vehicle axis must be offset from the source as if the source were being observed with a mirror.

The present design has two crystals, LiH and graphite, on either side of a large flat rotating table. The mirror angle with the telescope axis varies from 0.53 to 1.05 rad (30 to 60°) in 4.4×10^{-3} rad (1/4°) steps during observation periods; this corresponds to a vehicle motion of 1.05 to 2.1 radians (60 to 120°) in 8.8×10^{-3} rad (1/2°) steps. The actual observing program will concentrate upon weak sources and the steps will occur at approximately orbit intervals.

The crystal would be deployed after launch and would be stored to the side of the large area telescope when not in use. The crystal dimension results in about 10% loss of effective area at the 0.53 rad (30°) angle, and about 20% obscuration of the high resolution telescope at the 1.05 rad (60°) angle. The latter effect is not important as it is unlikely that the high resolution telescope would have a source to observe at the vehicle offset angle required by the objective crystal spectrometer.

The electronics for the objective crystal consists of a system to drive the crystal to a preset angle in 4.4×10^{-3} rad (1/4°) increments and a 15-bit (14.5×10^{-6} rad in 0.53 rad or 3 arcsec in 30°) shaft encoder. There is also a deployment and storage requirement. A redundant reset system will be provided.

The LiH crystal will consist of square modules, 5 cm (2 in.) by 5 cm by 1 cm thick, which must be sealed to avoid water contamination. The graphite crystals will be made in 5 cm hexagons 1.6 mm (1/16 in.) thick. The total crystal dimension is 2.5×1.3 m (98×51 in.); this will be supported by a stiffened honeycomb structure.

Alternatively, the mosaic may be placed at the focus of the large area telescope. A Johannson spectrometer with a spherically bent crystal with a radius of 0.5 m would be placed at the focus of the large telescope. Two crystals, a compacted graphite crystal for the 32 fJ to 64 fJ (2 to 4 keV) region, and an SHA (sorbital hexaacetate) crystal for the 16 to 32 fJ (1 to 2 keV) region, will be used.

This spectrometer will have lower resolution (500-1000) than the high resolution spectrometer, but its high efficiency combined with the high efficiency and large area of the Baez telescope will allow very weak lines to be detected. For brighter sources, a short scan would give a spectrum that could be used to determine the lines to be investigated by the high resolution spectrometer.

The compacted graphite can be thought of as composed of many slightly misaligned small perfect crystals. Neglecting absorption, X-rays penetrate the mosaic crystal until they strike a small crystalite oriented at the proper Bragg angle. Therefore, a spectrum within approximately $\pm 0.58 \times 10^{-3}$ rad (1/3°) of the Bragg angle setting of the crystal is dispersed on the focusing circle. A multi-wire proportional counter 1.3 cm (1/2 in.) wide by 1.9 cm (3/4 in.) high with wire spacings of 3.8 to 7.6×10^{-4} m (0.015 to 0.030 in.) placed at the focus will detect this dispersed spectrum. The wavelength range from 3×10^{-10} to 6×10^{-10} m (3 to 6 Å) will be scanned by rotating the crystal in 1/4° steps.

The 6×10^{-10} to 1.3×10^{-9} m (6 to 13 Å) range will be scanned with an SHA crystal, or a crystal with a similar 2d spacing, with a high peak reflectivity and a broad rocking curve of 8.75×10^{-4} rad (3 arcmin) or larger at 0.785 rad (45°) Bragg angle. The broad rocking curve insures that the entire line is reflected from the crystal even if it is Doppler broadened by high temperatures or high radial velocities. Because this crystal is not mosaic, only one or two wires in the proportional counter will be used to detect the reflected X-rays at the crystal focus. Because of the narrower rocking curve of this crystal, it will be scanned in 2.9×10^{-4} rad (1 arcmin) steps.

d. Polarimetry. The polarimetry experiment will use a graphite polarimeter or LiH polarimeter together with the large area X-ray telescope for polarization measurements of X-ray sources. Explanation of operation of polarimeters follows:

When soft X-rays are reflected through $\pi/2$ rad (90°), only the polarization component normal to the incident and reflected rays contributes effectively to the

reflected power; the component of the incident ray which is polarized parallel to the reflected ray is reflected with extremely low efficiency. The polarimeter design concept is that the X-rays are reflected through $\pi/2$ rad (90°) by a crystal with lattice planes oriented at $\pi/4$ rad (45°) to the telescope symmetry axis as shown in Figure 1-20.

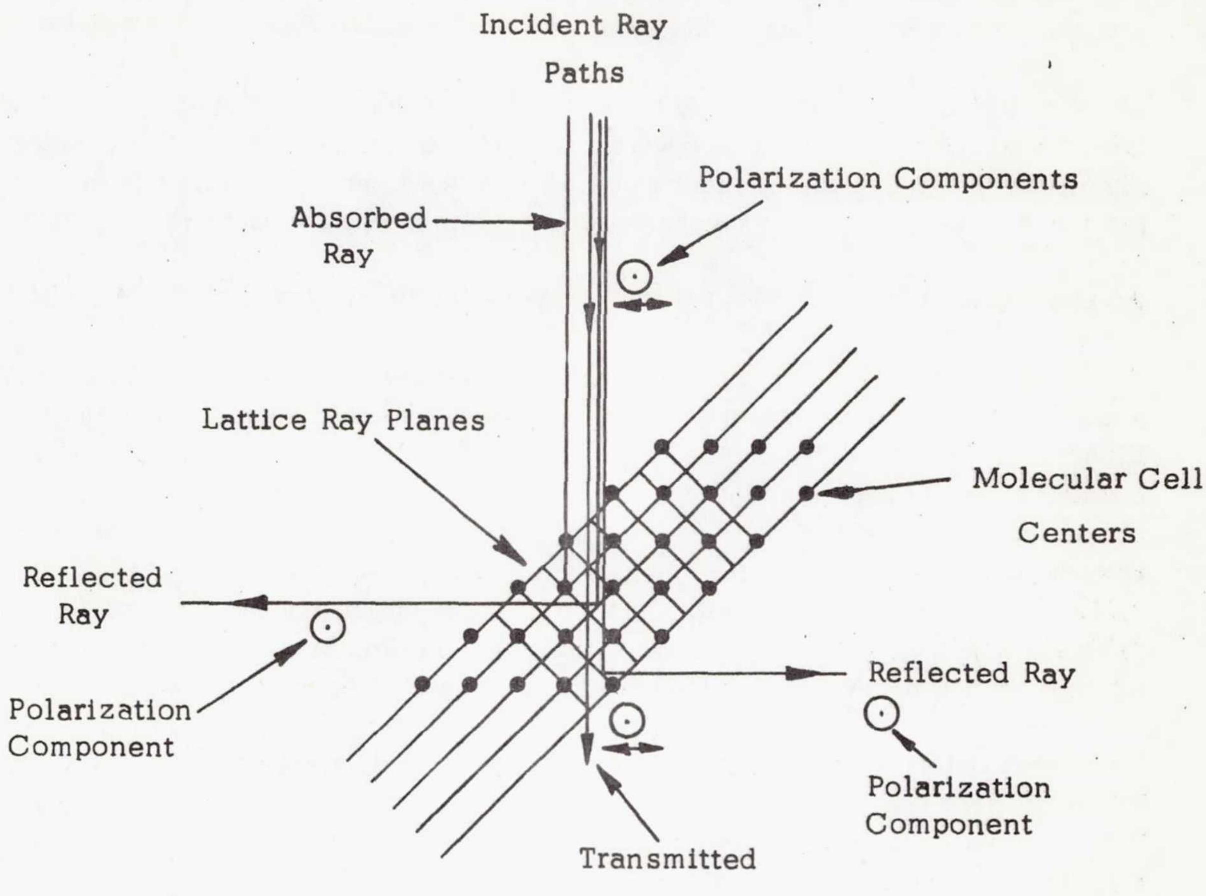


Figure 1-20. LiH Polarimeter Concept

The reflected ray is thus in the plane of the incident ray and the normal to the lattice planes at an angle of approximately $\pi/2$ rad (90°) with the incident ray. A data proportional counter is placed in the desired direction and polarization is detected by rotating the entire assembly around the telescope axis and measuring the reflected power as a function of angle. A polarized X-ray source will result in a maximum in the counting rate when the azimuthal angle is such that the plane of the incident X-ray crystal normal and the reflected ray are prependicular to the polarization of the incident ray.

Since the radiation must also satisfy Bragg's law for efficient reflection, only a narrow wavelength interval is efficiently reflected by a particular crystal. Tentatively two crystals, LiH and graphite, have been chosen; these crystals reflect energy of 4.30 and 2.62 keV respectively when the Bragg angle is $\pi/4$ rad (45°).

The LiH crystal has cubic symmetry, as illustrated in Figure 1-20; therefore, if the crystal is oriented so that radiation traveling in the axis direction is reflected in the +X direction, there will also be a set of lattice planes oriented so that radiation will be reflected into the -X direction. The same polarization component (the Z-axis component) contributes to both directions of reflection, and data counters are therefore included on both sides of the reflecting crystals. The graphite crystals do not have this symmetry and only one data counter can be used.

The crystals are purposely made quite thin so that the ray is unlikely to be absorbed after being reflected. Several crystals in series are thus required to reflect a significant portion of the incident radiation. A beam monitor counter is also placed after the crystals to measure the radiation passing through the crystals.

An electronics block diagram for the LiH polarimeter is shown in Figure 1-21.

Two proportional data counters, "A" and "B", as well as a Beam Monitor Counter are followed by typical proportional counter electronics including Pulse Shape Discriminators and Anticoincidence rejection circuits. The "A" and "B" data counter channels each terminate in 8-channel Pulse Height Analyzers. Each channel accommodates 10 bits or 1024 events. The Beam Monitor Counter electronics also terminates in an 8-channel Pulse Height Analyzer but with 13 bits or 8, 192 events per channel. Data Counter "A" and "B" channels each provide "Pulsar" mode capability by means of the Event Timing Marker which indicated whether or not an event has occurred during the past 1-msec time slot.

The entire detector is mounted on a rotating table that is capable of being scanned in one of three possible modes: (1) a full scan of 0 through 6.1 rad (0° through 350°) and back again; (2) continuous scan between any two selected angles; and (3) alternating between any two points which are $\pi/2$ rad (90°) apart. A 10-bit shaft encoder directly coupled to the rotating table will provide shaft position information. Up-link data commands for control of table motion, insertion and removal of a fixed focal plane aperture, and power supply control are required. The positioning system will utilize two codes interchangeably, thereby deriving the advantages of simplicity and lack of ambiguity. The position encoder will be a Gray Code device which changes only one bit between adjacent positions, thereby eliminating ambiguity at borderlines. The position will be commanded and processed in standard base-two binary code which has the advantages of simple serial comparison techniques and relatively simple human interface. The conversion from Gray to binary code is easy when done serially starting with the most significant digit.

The graphite polarimeter is electrically similar to the LiH instrument except for the lesser number of anticoincidence counters and the removal of the "B" data counter and its processing electronics. In all other respects, the instruments are electrically identical.

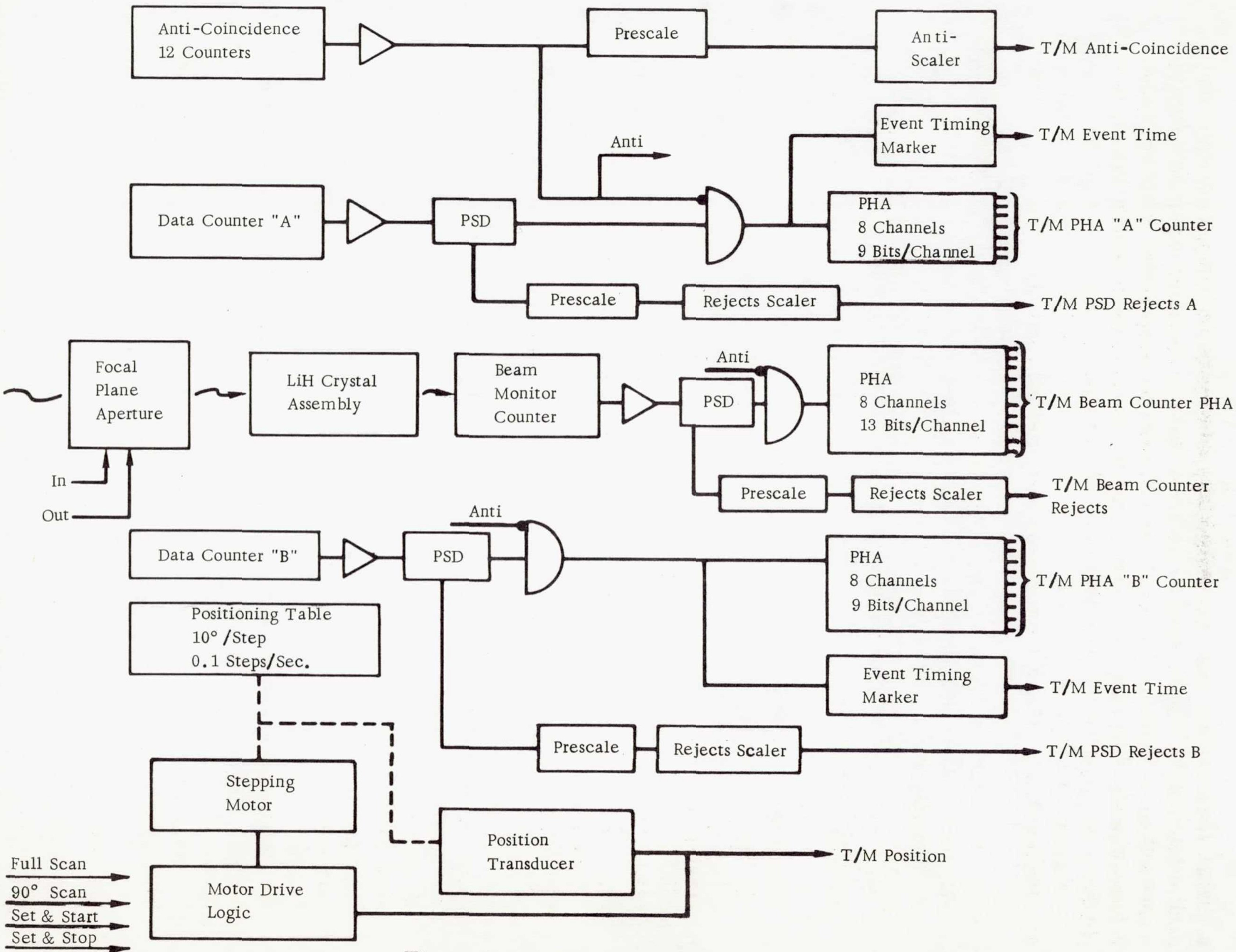


Figure 1-21. LiH Polarimeter

1.4.2.3 Observation Measurement Program. After initial setup, alignment, and calibration in space the large X-ray telescope and its associated experiment instruments will be deployed to its observation station by the supporting vehicle or module. A typical observation measurement program for use of experiment instruments to obtain information from a given X-ray source is listed below:

a. Preparation. (The observing location; controlled remotely.)

		Time/Minutes
1.	Observation direction selection and observation program input	5
2.	Remotely controlled equipment checkout (six instruments at 6 min/instrument)	36
3.	Offset reference guide stars selection (may be several sets in sequence as visible from orbit)	5
4.	Preorientation (slewing to guide star direction)	9 (max)
		55

b. Operations

1.	Guide or reference stars (2) acquisition	0.5
2.	Location of selected observation area for X-ray source via aspect sensing	0.5
3.	Focus and lock-on to selected source (via vernier adjustment of guidance - begin high angular stability hold mode)	0.5
4.	Observation and measurement program (if in direction perpendicular to orbit)	
	(a) maximum sensitivity detection	up to 100 min
	(b) interchange to next experiment package	2
	(c) realign or refocus adjustment	1
	(d) position-sensitive proportional counter imaging	up to 100 min
	(e) interchange to next experiment	2
	(f) readjust or refocus	1
	(g) mosaic spectrometry measurements	up to 100 min
	(h) interchange to next experiment	2
	(i) readjust or refocus	1
	(j) polarimetry with LiH polarimeter	up to 100 min
	(k) interchange to next experiment	2

		Time/Minutes
(l)	readjust or refocus	1
(m)	polarimetry with graphite polarimeter	up to 100 min
(n)	total observation and interchange cycle per source, if all instruments are used	513.5 min. (8.56 hr)
(o)	total preparation, observation and interchange cycle if all instruments are used	568 min (9.47 hr)
(p)	repeat as necessary	
(q)	transfer to next source by using preparation cycle	55

The sequence may be reduced to a total of 2.14 hours if observation time per instrument of only 10 minutes is used, such as on a strong source. Obviously, unless the source of interest is roughly perpendicular to the orbital plane of the experiment carrier vehicle, the long total observation times indicated might not be possible in a continuous period. Then the observation measurement task might be broken up into lesser duration periods.

1.4.2.4 Interface, Support, and Performance Requirements. The large-area moderate-resolution X-ray experiment interface, support, and performance requirements are tabulated in Table 1-9. Data rates shown under science/exp are the information output rates resulting after partial internal information processing within the facility equipment items.

The desired inclination for an optimum survey of the galaxy would be one perpendicular to the galactic plane, with an altitude sufficiently great to reduce obscuration by the Earth. Thus, the optimum inclination would be approximately 28.5 degrees.

The South Altantic Anomaly radiation introduces a significant increase in the noise level of the detectors, hence reducing the detectability of the experiments. Currently, there is not enough detail available on the detectors for a quantitative analysis, but it is expected to be severe enough to compromise the usefulness of the experiment. For sensitive experiments, permanent damage could occur, according to recent estimates, when more than 1 millirad per hour is experienced at energies greater than 8 nJ (0.5 meV).

Previous tests have shown that the experiment detectability is not compromised by the Earth's atmosphere at altitudes of 370 to 740 km (200 to 400 n.mi.) and higher. The South Atlantic Anomaly extends downward to about 555 km (300 n.mi.) at latitudes greater than 30°. To escape the South Atlantic Anomoly and to maximize continuous

Table 1-9. Large Area Moderate Resolution X-Ray Telescope Experiment Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	x. Aspect Sensing	a. Maximum Sensitivity Detection	b. Position Sensitive Propor. Counter Array Experiment	c. Mosaic Spectrometry	d. Polarimetry	e. Experiment Interchange, Checkout and Alignment			ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	Aspect Optics Aspect Detector High Resolution X-ray Telescope Structure	Large Area X-ray Telescope Max Sensitivity Solid State Detector	Large Area X-ray Telescope Proportional Counter Array	Large Area X-ray Telescope Mosaic Crystal Spectrometer Array Proportional Counter Array	Large Area X-ray Telescope LiH Polarimeter Graphite Polarimeter	Experiment Interchange Equipment Alignment and Checkout Equip.			a, b, c, d	Peal: loading of a, x + b, c, d
Launch Mass, kg (Weight, lb)	63.5 (+140)	2132 + 29.5 (4700 + 65)	2132 + 29.5 (4700 + 65)	2132 + 29.5 + 294 (4700 + 65 + 649)	LiH: 2132 + 40 (4700 + 88) Graphite: 2132 + 38 (4700 + 84)				2546 (5612)	2546 (5612)
Logistics Support										
Consumables, kg/180D (lb/180D)		20 (44)							20 (44)	20 (44)
Spares, kg/180D (lb/180D)	6.8 (15)	16 (35)	16 (35)	16 (35)	22.7 (50)	22.7 (50)			100 (220)	100 (220)
Crew Support										
Initial Setup, Manhours/180D	0.5	2	2	2	2	—			8	8.5
Periodic Serv. & Maint., Manhours/180D	0.5	2	1	2	2	3 × 0.5			7.4	7.4 + observation from prep 0.92 hrs
Operation, Remote Control, Manhours/Observation Cycle	0.1	Up to 1.66	Up to 1.66	Up to 1.66	Up to 1.66	Up to 0.5 exp			0.6 to 2.14	0.6 to 9.5
Electric Power:										
Peak Load, Watts	21.08	200	20	17 + 14.77	LiH - 33.87 Graphite - 28.30				223.87	Max. Comb. a + b. 223.87
Average Load, Watts	18.36	200	14.77	2 + 14.77	LiH - 30.87 Graphite - 25.30				220.87	220.87
Standby Load, Watts	18.36 (In parallel oper.)	190 Either in ops or standby	14.77		LiH - 30.87 Graphite - 25.30				190	190
Environmental Control										
Desired Vehicle Heat Sink Temp, °K	273 ± 10	273 ± 10	273 ± 10	273 ± 10	273 ± 10				273 ± 10	273 ± 10
Temp. Limits, Stowed, °K	253 to 309	263 to 293	263 to 293	263 to 293	263 to 293					
Temp. Range, Ops., °K	286 to 290	272 to 274	272 to 274	272 to 274	272 to 274				272 to 274	272 to 274
Max. Temp. Difference, °K	2	2	2	2	2				2	2
Relative Humidity, %	< 40	< 40	< 40	< 40	< 40				< 40	< 40
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 (0 to 15)	1.33×10^{-4} (10^{-6} Torr) ops	1.33×10^{-4} (10^{-6} Torr ops)	1.33×10^{-4} ($<10^{-6}$ Torr) ops	1.33×10^{-4} ($<10^{-6}$ Torr) ops	1.33×10^{-4} ($<10^{-6}$ Torr) ops			1.33×10^{-4} ($<10^{-6}$ Torr) ops	1.33×10^{-4} ($<10^{-6}$ Torr) ops
Cleanliness Class	100,000	10,000	10,000	10,000	10,000				100,000	10,000
Gravity Level, Max. g	$<10^{-3}$, operating	Space vacuum defl. within toler.	Space vacuum defl. within toler.	Space vacuum defl. within toler.	Space vacuum defl. within toler.				$<10^{-3}$	Keep angular defl. within tolerance
Radiation Sensitivity, millirad/hr	< 1	< 1	< 1	< 1	< 1				< 1	< 1
Contamination Sensitivity	Moderate	Moderate	Moderate	Moderate	Moderate				Out of contamination cloud, free flying	Out of contamination cloud, free flying

*Point where devices become radioactive.

Table 1-9. Large Area Moderate Resolution X-Ray Telescope Experiment Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS \ EXPERIMENT	x. Aspect Sensing	a. Maximum Sensitivity Detection	b. Position Sensitive Proportional Counter Experiment	c. Mosaic Spectrometry	d. Polarimetry	d. Polarimetry (cont.)	e. Experiment Interchange, Checkout and Alignment			ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:											
Desired Inclination, deg	0	0	0	0	0					-	0
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0					55 to 0	-
Desired Altitude, km	740 to 930	740 to 930	740 to 930	740 to 930**	740 to 930**						740 to 930
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)						(400 to 500)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740					370 to 740	-
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)					(200 to 400)	
Orientation:											
Observed Object Location	via reference stars	via reference stars	via reference stars	via reference stars	via reference stars					-	via reference stars
Observed Object Brightness, mag., m_v	8	10^{-6} Sco X-1	10^{-5} Sco X-1	$<10^{-3}$ Sco X-1	$<10^{-3}$ Sco X-1					10^{-6} to 10^{-3} Sco X-1	10^{-6} to 10^{-3} Sco X-1
Observation Field of View	4.82×10^{-2} rad (2.742°)	3.5×10^{-2} rad (2°)	3.5×10^{-2} rad (2°)	Center portion of 3.5×10^{-2} rad (2°) FOV	Center portion of 3.5×10^{-2} rad (2°) FOV						
Pointing Accuracy, rad	5×10^{-6}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}	2.9×10^{-4}					2.9×10^{-4}	2.9×10^{-4}
(arcsec)	(≤ 60, pref. 1)	(≤ 60)	(≤ 60)	(≤ 60)	(≤ 60)					(≤ 60)	(≤ 60)
Pointing Stability, rad/obs time	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}					5×10^{-6}	5×10^{-6}
(arcsec/obs time)	(≤ 1)	(1)	(1)	(1)	(1)					(1)	(1)
Slew Rate, max., rad/sec	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}					2.6×10^{-3}	2.6×10^{-3}
(arcsec/sec)	(≤ 540)	(≤ 540)	(≤ 540)	(≤ 540)	(≤ 540)					(540)	(540)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}					5×10^{-6}	5×10^{-6}
(arcsec/sec)	(≤ 1)	(1)	(1)	(1)	(1)					(1)	(1)
Pointing Hold Time, sec (uninterrupted)	Up to 6000 In parallel	Up to 6000	Up to 6000	Up to 6000	Up to 6000					6000	6000
Data Requirements/Observation Cycle:					Polarimeters: LiF	Graphite					
Spectral Range Meters	8×10^{-7} to 3×10^{-7}	10^{-8} to 2×10^{-10}	10^{-8} to 2×10^{-10}	1.3×10^{-9} to 3×10^{-10}	2.9×10^{-10}	4.77×10^{-10}				-	-
Å	(8000 to 3000)	(100 to 2)	(100 to 2)	(13 to 3)	(2.9)	(4.77)					
(keV)		(0.124 to 6.2)	(.0.124 to 6.2)	(1 to 4)	(~4.30)	(~2.63)					
Imaging Data										For Cross Correlation on board	For Cross Correlation on Board
Desired Resolution, (spatial or spectral)	Selectable: 1, 7.46		2 to 10							2 to 10	1, 7.46
Equiv. Image Format Size, mm	24×24	-	-	-						24×24	24×24
Picture Elements/Image	1,048,576	-	-	-						1,048,576	1,048,576
Images/Data Set											
Images/Second	1	-	-	-						1	1
Photometric Resolution, %, bits	1, 7	-	-	-						1, 7	(1, 7)
Equiv. Analog Data, MHz	11, optional	-	-	-						(11, optional)	(11, optional)
Equiv. Digital Data, bits/image	7.343×10^6	-	-	-						7.343×10^6	(7.343×10^6)
Non-Imaging Data: Command Data, bps***	6	10	6	13 + 6	20	20				Max. 20	20
Science/Exp. Data, bps	250	300	5352	5352	2286	1199				5352	5352
Housekeeping Data, bps	15	8	8	2 + 8	6	6				53	53
Special Requirements:											
Updating Cycle, Years	2	2	2	5	2	2				2 to 5	2 to 5
Mass, kg/yr	5.7	14.8	14.8	14.8	20	19				134	134
(Weight, lb/yr)	(12.5)	(32.5)	(32.5)	(32.5)	(44)	(42)				(293.5)	(293.5)
Volume/Year, kg	2.83×10^{-2}	5.7×10^{-2}	5.7×10^{-2}	5.7×10^{-2}	5.7×10^{-2}	5.7×10^{-2}				31.33×10^{-2}	31.33×10^{-2}
(lb)	(1)	(2) Detector cooled to ~ 77°K	(2)	(2)	(2)	(2)				(11)	(11)

**When possible, observation should be made at altitudes greater than 4000 km, entirely out of Van Allen belts.

***On-board information processing built into the equipment to some extent.

observation time under the Van Allen Belts, a 740 to 930 km (400 to 500 n.mi.), 0° inclination orbit is preferred. This higher altitude also compensates for the increased atmospheric drag encountered in equatorial orbit.

1.4.3 PROPORTIONAL COUNTER ARRAY EXPERIMENTS

1.4.3.1 Scientific or Technical Objectives. Many of the X-ray objects have a substantial flux in the 16 to 160 fJ (1 to 10 keV) X-ray range which makes possible their observation with conventional proportional counters. The performance of such counters is well understood. They can be constructed to be stable over long periods of time and can be properly calibrated over their range of energy sensitivity. Several important applications can be recognized for an array of counters looking along the same axis as telescopes. In contrast with the proportional counters, it may not be possible to guarantee the stability of many of the other instruments in this facility; thus, the proportional counters provide a cross-calibration when viewing common targets. This is particularly important since many of the X-ray sources are known to vary and cannot themselves serve for purposes of calibration. Also, in looking for time variability, particularly for stronger sources, such an array can have very high counting rates and thus be more sensitive to small changes in intensity than the telescope instruments.

1.4.3.2 Description

a. Cross-Calibration of Other Experiments. The proportional counter array described in Section 1.2.3 is utilized to provide independent correlation data in the 1 keV range. The equipment is run in parallel with the other telescopes as an energy collector; information obtained is partially processed prior to release to supporting vehicle.

b. Time Variability of Strong Signals. Pulsating or varying X-ray flux sources are identified and time correlated to 1 msec by special equipment built into the Proportional Counter Array described in Section 1.2.3. Such transient phenomena can also be made to give an alarm enabling the high resolution X-ray imaging experiment to search for the source of the rapidly varying phenomena and to switch into Mode B at 1024 frames per second. (See Section 1.4.1.2.)

1.4.3.3 Observation/Measurement Program. The large proportional counter array is operated continually in parallel with the other experiment equipment such as the two X-ray telescopes, the scintillation counter, and the crystal spectrograph to enable cross-calibration of those experiments in intensity readings and to mark the occurrence of rapidly varying phenomena. Typical observation times per source, per experiment run, will extend up to 6000 seconds (100 minutes). Total use for the six concurrently operating energy collectors may extend to 97.5 hours per source.

1.4.3.4 Interface, Support, and Performance Requirements. Interface, support, and performance requirements for the large proportional counter array are shown in Table 1-10 in Section 1.5.

1.4.3.5 Potential Role of Man. The large proportional counter array is automatic and requires little manned support, after initial checkout, except for periodic maintenance and calibration at six-month intervals.

Scientists at remote control positions in a Space Station or on the ground will periodically note operation of the counter array as well as significant transient effects (as indicated by alarm). Information processing of primary experiment data will utilize proportional counter array data to modify results for extraneous variations as well as to complement primary X-ray telescope data where primary instrument coverage is not available.

1.4.3.6 Available Background Data

a. Report No. ASE-2266A, Preliminary Study: Telescopes and Scientific Subsystems for a High Energy Astronomy Observatory, rev. 26 September 1969.

b. NASA SP-213, A Long Range Program in Space Astronomy, July 1969.

1.4.4 SCINTILLATION COUNTING

1.4.4.1 Scientific or Technical Objectives. The purpose of the scintillation counter is to extend correlation of incoming soft X-ray radiation to higher energy phenomena.

1.4.4.2 Description. The scintillation counter assembly as described in Section 1.2.4 will be employed to register high energy phenomena which affect the primary experiments accomplished with the two X-ray telescopes.

1.4.4.3 Observation/Measurement Program. Observation/measurements will be accomplished in parallel with experiment operations described in Section 1.4.2.3; a maximum observation period may be as large as 100 minutes per particular type observation or measurement. Total time per source may extend to 9.5 hours.

1.4.4.4 Interface, Support, and Performance Requirements. The scintillation counter assembly will be operated at the same time as primary X-ray telescope experiments to enable cross-correlation of information in different parts of the X-ray spectrum. Scintillation counter experiment interface, support, and performance details may be found in Table 1-10 in Section 1.5.

1.4.4.5 Potential Role of Man. Man ultimately aids in interpretation and correlation of data obtained by the scintillometer with the phenomena found in the primary X-ray experiments data. Outside of initial setup and periodic maintenance, man has little direct function in the scintillometer observation process except for periodic checks to note whether the instrument is operating properly.

1.4.5 CRYSTAL SPECTROMETER EXPERIMENTS

1.4.5.1 Scientific or Technical Objectives. The highly ionized calcium and iron lines, believed to be strong lines in the 4.1×10^{-10} m to 7×10^{-11} m (3 to 18 keV) region, will be observed. Also, because of the high sensitivity of the flat crystal spectrometer and because it will observe the source continuously, very weak lines from the stronger sources could be observed, giving important information on the composition of strong X-ray sources and the production of heavy elements.

Doppler shifts and broadening of about 1 part in 10^4 will be observed, thereby allowing source temperatures and velocities to be obtained. Temperatures and information on production mechanisms will be obtained from the relative strengths of different ionization states.

1.4.5.2 Description

a. Higher Energy Spectroscopy. The flat crystal spectrometer will be used to obtain fairly high-resolution spectral data in the 6×10^{-9} to 10^{-10} meter (60 Å to 1 Å) region to complement the high resolution spectrometer experiment described in Section 1.4.1, particularly at wavelengths less than 10^{-9} m (10 Å). Since it substitutes for part of the primary experiments but can be run at the same time, it will require either ground crew or scientist/astronaut attention via monitoring and command links.

b. Doppler Shift/Source/Temperature/Velocity Measurements. The doppler shifts and broadening of incoming X-ray radiation within the spectral range of the instrument can be measured to 1 part in 10^4.

1.4.5.3 Observation Measurement Program. Observation measurement preparation and time of operation will be as follows:

a.	Preparation (remote control adjustment and positioning)	15 minutes
b.	One scan, 6×10^{-9} to 10^{-10} m (60 Å to 1 Å)	12.5 minutes
c.	Repeat scan as necessary	12.5 min each
d.	Transfer to next source and operate parallel with X-ray telescope experiments schedule (requires 55 minutes for large-area array telescope plus 568 minutes for experiments, a total of 9.5 hours per source.	

1.4.6 TRANSIENT X-RAY PHENOMENA DETECTION EXPERIMENT

1.4.6.1 Scientific or Technical Objectives. There is presently considerable evidence to the effect that extra-solar X-ray emission of transient nature may be frequent, be it the appearance in the sky of a new source (i.e., nova outburst), a large flare in a

nearby stellar object, or temporal variations of existing X-ray sources. It is mandatory that provision be made for the early detection of such possible flareups for the benefit of the more elaborate experiments at the focus of the telescope(s). The requirements for a detection system may be stated as follows:

a. All-sky coverage at all times.

b. Spatial resolution as needed to guide the pointing of other instruments and for obtaining high sensitivity.

c. Low internal detector background, also required for achieving high sensitivity.

1.4.6.2 Description. The transient phenomena detector array will be used to identify presence, angle of arrival, and spectral distribution of transient X-ray phenomena which may adversely affect the X-ray telescopes and their instruments.

The array, described in Section 1.2.6, is expected to operate continuously while other instruments are functioning; the transient X-ray phenomena will be correlated with X-ray telescope results.

Present indications are that the intrinsic detector background of multi-anode proportional counters at 370 to 740 km (200 to 400 n. mi.) altitudes is rather flat and of the order of 10^{-3} cm^{-2} sec^{-1} keV^{-1}. This is more than one order of magnitude smaller than the contribution of the diffuse radiation. Thus, it is the latter which will most likely limit the sensitivity of the proposed detector unless it becomes possible to increase the number of anodes considerably.

The equivalent sensitivity of the detector array is $(dN/dE) = 0.026$ cm^{-2} sec^{-1} keV^{-1}. For a source having spectral shape similar to that of Sco X-1, the above intensity is 300 to 400 times below the corresponding Sco X-1 intensity. The threshold intensity for Crab-like X-ray spectra is about 20 times below Tau XR-1. This sensitivity may be increased by taking a wider energy band and by accumulating data for longer periods of time.

1.4.6.3 Observation/Measurement Program. The transient phenomena detector array will remain operating during operation of all X-ray astronomy experiments, which can extend to 9.5 hours per experiment series sequencer. The detector array will provide identification of transients as well as gross direction-finding, enabling interpretation of transients in the primary experiment data as coming from the source observed or from some other external source.

1.4.6.4 Interface, Support, and Performance Requirements. Interface, support, and performance requirements for the transient X-ray detection array will be found in Table 1-10 in Section 1.5. It requires a location (somewhere behind the X-ray telescope focal point) in the spacecraft that is capable of seeing the upper hemisphere with

respect to the orbit tangent plane. Of course blockage will occur in the direction of the X-ray telescope mirrors. Perhaps the four panels will need to be distributed or extended in space around the periphery of the experiment facility supporting vehicle.

1.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

The accumulated FPE interface, support, and performance requirements are described in Table 1-9.

The total experiment may be packaged for transport in a length of 9 meters (30 feet) within a cylindrical cross-section of 2.6 meters (102 in.). A section of the focal volume of the large-area moderate-resolution X-ray telescope is extended backward through the aft end FPE cylindrical volume. Where possible, 4.57 meters (15 feet) of the total 13.5 meters (45 feet) of the large X-ray telescope should be provided as an inset volume in the supporting vehicle.

1.6 POTENTIAL MODE OF OPERATION

The X-ray stellar astronomy FPE is best operated in a free-flying module away from a large Space Station with its potential sources of radiation and contamination cloud. Initially, the experiment facility equipment will require fairly frequent visits to a supporting Space Station or visits from a Space Shuttle or other servicing vehicle to gradually get all the equipment working and cross-calibrated. Eventually, as techniques are developed, the experiment facility equipment is expected to be serviced about once per six months. Operational control will be primarily from a ground station with an appropriate astronomer observer staff.

The six sets of experiment facility equipment will operate at the same time. However, individual experiments for each of the X-ray telescopes, except for aspect sensing, will be sequenced into the focal point one at a time. Aspect sensing will be accomplished at the same time as one of the X-ray telescope experiments, either for additional image stabilization or for obtaining visible light and ultraviolet correlation information. Both X-ray telescopes will operate at the same time, with the other four facility equipments supplying error correction, transient identification, or additional spectral information about the sources observed in finer detail by the telescopes.

If the Space Station or servicing vehicle contains radioactive sources, such as a nuclear electric or radioisotope power source, provisions should be made in the experiment carrier vehicle to protect the elements of the X-ray astronomy equipment which might become radioactive when subjected to high energy, high radiation fluxes. Likewise, some form of protection is desired when passing through the high-flux South Atlantic Anomaly or the Van Allen belts.

The application of this experiment package to each of the proposed mission modes is as follows:

Table 1-10. X-Ray Stellar Astronomy FPE Interface, Support, and Performance Requirements

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	1.4.1 High Resolution X-ray Telescope Experiments	1.4.2 Large Area Moderate Resolution X-ray Teles. Exps	1.4.3 Large Proportional Counter Array Experiments	1.4.4 Scintillation Counting Experiments	1.4.5 Crystal Spectrograph Experiments	1.4.6 Transient X-ray Phenomena Detection			MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	X-ray Telescope Aspect Optics Aspect Detector Imaging Detector Transmission Grating Crystal Spectrometer Filter Wheel	Large X-ray Telescope Aspect Optics Hi Sensitive Solid State Detector Proportional Counter Mosaic Crystal Polarimeter	Large Proportional Counter Array	Scintillation Counter Assemb.	Crystal Spectrograph	Transient Phenomena X-ray Detection Array			5.1.1.4.1 +5.1.1.4.2 +5.1.1.4.3 +5.1.1.4.4 +5.1.1.4.5	5.1.1.4.1 +5.1.1.4.2 +5.1.1.4.3 +5.1.1.4.4 +5.1.1.4.5 +5.1.1.4.6
Launch Mass, kg (Weight, lb)	1218 (2686)	2546 (5612)	89 (196)	144 (318)	62 (137)	181 (400)			4040 (8906)	4239 (9346)
Logistics Support										
Consumables, kg/180D (lb/180D)	-	20 (44)	-	-	-	-			20 (44)	-
Spares, kg/180D (lb/180D) **	75.7 (167)	66.5 (146.7)	-	-	-	-			142.7 (313.7)	-
Crew Support										
Initial Setup, Manhours/180D	2.5	8.5	2	2	2	2			-	19
Periodic Serv. & Maint., Manhours/180D	2.5	7.5	2	2	2	2			-	18
Operation, Remote Control, Manhours/Observation Cycle	1.6 to 3.24 in parallel with tele.	1.6 to 9.5	0.1*	0.1*	0.22 to 1.66*	0.1*			1.71/Op Cycle	14.7 in 9.5 hr
Electric Power:										
Peak Load, Watts	254	223.87	29.3	10.8	12.04	36			525.26	525.26
Average Load, Watts	172	220.87	29.3	10.8	12.04	36			452.76	452.76
Standby Load, Watts	72	190	-	-	-	-			262	262
Environmental Control										
Desired Vehicle Heat Sink Temp, °K	273 ±10	273 ± 10	273 ± 10	273 ±10	273 ± 10	273 ± 10			-	273 ±10
Temp. Limits, Stowed, °K	253 to 309	263 to 293	263 to 293	263 to 293	263 to 293	263 to 293			263 to 293	263 to 293
Temp. Range, Ops., °K	286 to 290	272 to 274	272 to 274	272 to 274	272 to 274	-			272 to 274	272 to 274
Max. Temp. Difference, °K	2	2	4	2	2	10			2	2
Relative Humidity, %	< 40	<40	< 40	< 40	< 40	< 40			< 40	< 40
Atmosphere Limit, N/m^2	0 to 10^5	0 to 10^5, < 1.33 x 10^{-4}	0 to 10^5, < 1.33 x 10^{-4}	0 to 10^5, <1.33 x 10^{-4}	0 to 10^5, <1.33 x 10^{-4}	0 to 10^5, < 1.33 x 10^{-4}			0 to 10^5	< 1.33 x 10^{-4}
(psi)	(0 to 15)	(0-15), <10^{-6} torr)	(0-15), <10^{-6} torr)	(0-15), <10^{-6} torr)	(0-15), <10^{-6} torr)	(0-15), <10^{-6} torr)			(0-15)	(<10^{-6} torr)
Cleanliness Class	100,000	10,000	-	-	-	-			100,000	space vacuum
Gravity Level, Max. g	<10^{-4}, when ops	< 10^{-3}	-	-	-	-			< 10^{-3}	preferred < 10^{-4}
Radiation Sensitivity, millirad/hr	< 1	< 10	1	-	-	-			-	< 10^{-3}
Contamination Sensitivity	Moderate	Moderate	Slight	Slight	Slight	-			Moderate	Moderate

* These instruments operate continuously at same times as experiments in 5.1.1.4.1 and 5.1.1.4.2; manhours shown cover only part of actual observation period.

** See special requirements updating for periodic equipment exchanges with updated and maintained units.

Table 1-10. X-Ray Stellar Astronomy FPE Interface, Support, and Performance Requirements (Continued)

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	1.4.1 High Resolution X-ray Telescope Experiments	1.4.2 Large Area Moderate Resolution X-ray Teles. Exps	1.4.3 Large Proportional Counter Array Experiments	1.4.4 Scintillation Counting Experiments	1.4.5 Crystal Spectrograph Experiments	1.4.6 Transient X-ray Phenomena Detection			MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	0	0	0	0	0	0			-	0
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0			55 to 0	55 to 0
Desired Altitude, km	740 to 930	740 to 930	740 to 930	740 to 930	740 to 930	740 to 930			-	740 to 930
(n.mi.)	(400 to 500)	(400 to 500)	(400 to 500)	(400 to 500)	(400 to 500)	(400 to 500)			-	(400 to 500)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740			370 to 740	-
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)			(200 to 400)	
Orientation:										
Observed Object Location	via reference stars	via reference stars	parallel with teles.	parallel with teles.	parallel with teles.					via reference stars
Observed Object Brightness, mag., m_v	10^{-6} Sco X-1 to Sco X-1	10^{-6} Sco X-1 to Sco X-1	Sco X-1 to 10^{-4} Sco X-1	Sco X-1 to 10^{-4} Sco X-1	Sco X-1 to 10^{-4} Sco X-1	$< 0.5 \times 10^{-3}$ Sco X-1				-
Observation Field of View	1.16×10^{-3} rad (4 arcmin)	3.5×10^{-2} rad (2°, 7200 arcsec)	1.74×10^{-2} rad (1°, 3600 arcsec)	8.7×10^{-2} rad (5°, 18000 arcsec)	1.05×10^{-2} rad (36 arcmin)	2π steradians				-
Pointing Accuracy, rad	2.9×10^{-4}	2.9×10^{-4}, 5×10^{-6}	1.75×10^{-3}	175×10^{-3}	1.75×10^{-3}	1.75×10^{-3}			2.9×10^{-4}	5×10^{-6}
(arcsec)	(≤60)	(≤60, 1)	(360)	(360)	(360)	(Ref to 360)			(≤60)	(≤1)
Pointing Stability, rad/obs time	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}			5×10^{-6}	5×10^{-6}
(arcsec/obs time)	(≤1)	(≤1)	(≤1)	(≤1)	(≤1)	(≤1)			(≤1)	(≤1)
Slew Rate, max., rad/sec	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}	2.6×10^{-3}			2.6×10^{-3}	2.6×10^{-3}
(arcsec/sec)	(540)	(540)	(540)	(540)	(540)	(540)			(540)	(540)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}	-	-	-	-			5×10^{-6}	5×10^{-6}
(arcsec/sec)	(<1)	(1)	-	-	-	-			(1)	(1)
Pointing Hold Time, sec	Up to 6000	Up to 6000	Up to 6.64 hr/Exp. Cycle	Up to 6.64 hr/Exp. Cycle	Up to 6.64 hr/Exp. Cycle	Up to 6.64 hr/Exp. Cycle			2700 to 6000	6000 per Teles. Exp
Data Requirements/Observation Cycle:										
Spectral Range	10^{-8} to 2×10^{-10} m (100 to 2Å) (0.124 to 6.2 keV)	10^{-8} to 10^{-10} m (100 to 1 Å) (0.124 to 12.4 keV)	1.2×10^{-9} to 1.2×10^{-10} m (12 Å to 1.2 Å) (1 to 10 keV)	1.2×10^{-10} to 4×10^{-12} m (1.2 Å to 0.04 Å) (10 to 300 keV)	1.2×10^{-10} to 6×10^{-11} m (1.2 Å to 0.6 Å) (10 to 20 keV)	1.8×10^{-9} to 6×10^{-11} m (18 Å to 0.6Å) (0.8 to 20 keV)				
Imaging Data		Cross-correlation Aspect Sensing Ref to 5×10^{-6} rad, 10^{-11} m (1 arcsec, 0.1Å)								
Desired Resolution, (spatial or spectral)	5×10^{-6} rad, 10^{-11} m (1 arcsec, 0.1 Å)									maximum: 5×10^{-6} rad, 10^{-11} m (1 arcsec, 0.1Å)
Equiv. Image Format Size, mm	24 x 24	(24 x 24)	-	-	-	-			-	-
Picture Elements/Image	1,048,576	(1,048,576)	-	-	-	-			-	-
Images/Data Set	-	-	-	-	-	-			-	-
Images/Second	16, 64, 256, 1024	1	-	-	-	-			-	-
Photometric Resolution, %, bits	1, 7	1, 7								
Equiv. Analog Data, MHz	11, optional	11, optional	-	-	-	-			-	-
Equiv. Digital Data, bits/image	up to 1.19×10^{8}	7.343×10^{6}	-	-	-	-			7.34×10^{6}*	Optional 1.2×10^{8}*
Non-Imaging Data: Command Data, bps	40	20	8	8	24	32			40	64 to 140
Science/Exp. Data, bps	25000	5360	2210	830	3627	-			-	37,312
Housekeeping Data, bps	415	53	-	-	-	-			-	-
Special Requirements:										
Updating Cycle, Years	2	2 to 5	2	2	5	2			-	2 to 5
Mass, kg/yr (Weight, lb/yr)	65 (143.5)	133 (293.5)	89 (196)	144 (318)	62 (137)	181 (400)			676 (1490.6)	676 (1490.6)
Volume, m^3/yr (ft^3/yr)	0.27 (9.6)	0.31 (6)	0.31 (9.66)	0.23 (8)	0.58 (20.3)	0.2 (7.2)			1.73 (60.8)	1.73 (60.8)
Supporting Vehicle Data Storage for 100 minutes, bits										2.2×10^{8}
Playback Rate, bps (average of observation and nonobservation time)										7.5×10^{5}

* Periodic readout for guiding and reference purposes.

Mission A - Limited On-Orbit Stay Time With Space Shuttle. This mission does not appear useful for the large X-ray telescope because of the short on-orbit stay time and the need for many hours of observation to accomplish the scientific objectives.

Mission B - Extended Orbit Stay Time Revisited By A Shuttle. This is the desired mode of operation for this FPE. The RAM/X-ray telescope will be launched by the Shuttle and checked out in orbit. If all basic systems are satisfactory, it will be deployed for extended observations. If any critical system is not functioning properly it will be repaired, if possible; if not, the entire package can be returned to Earth for overhaul. Resupply of the cryogenics will be required at least every 18 months, and maintenance and repair can be accomplished at that time. It can be revisited sooner in the event of major failure.

Mission C - Extended Mission In Conjunction With Space Station. Since remote operation is the preferred mode, and frequent visits do not appear to be necessary or even advisable, this mode does not offer any real advantage over Mission B. Location of the Space Station in the near vicinity could actually be detrimental due to contamination.

1.7 SCHEDULES

The schedule in Table 1-11 is predicted for development of the X-ray stellar astronomy equipment.

1.8 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

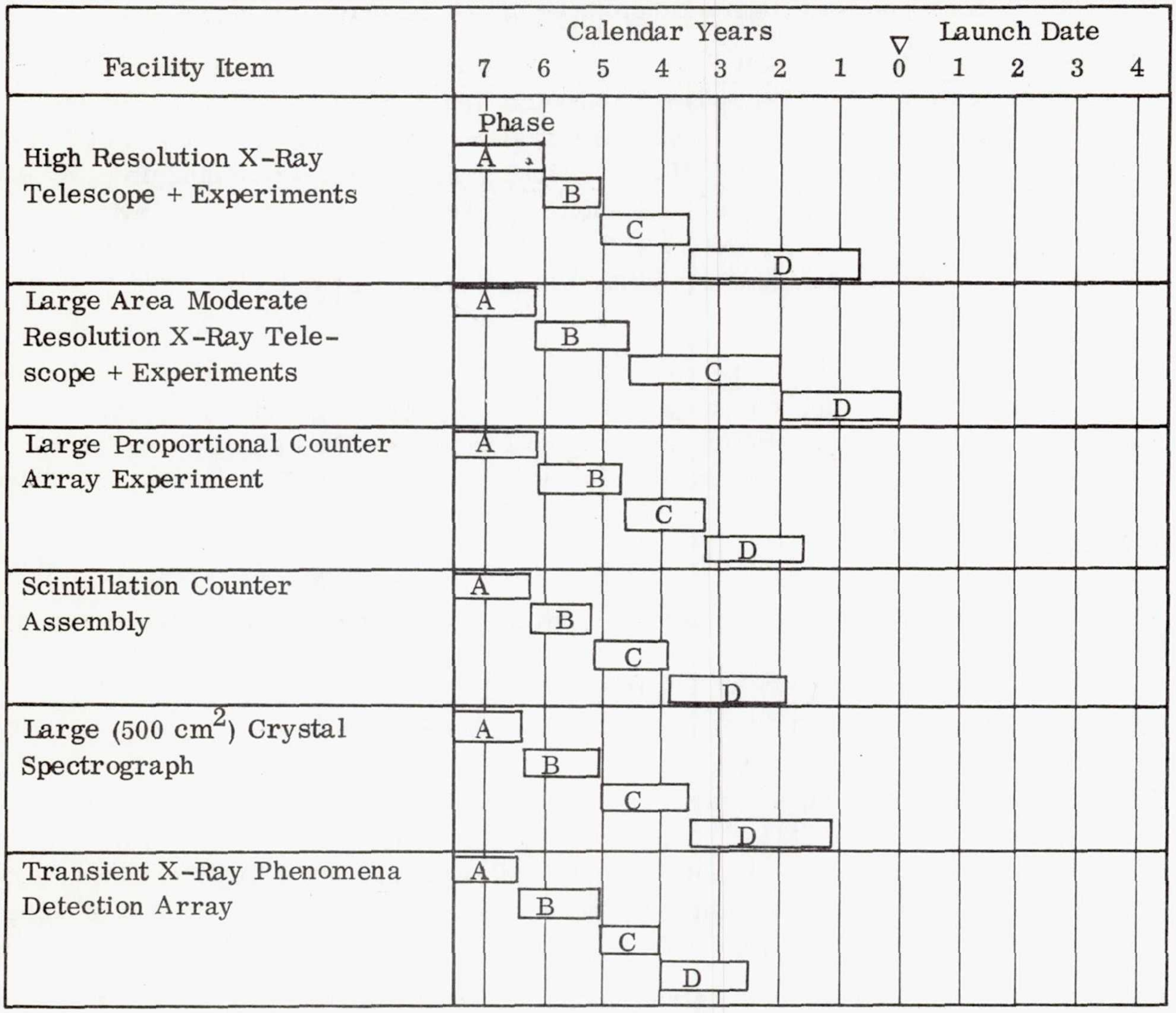
The following prelaunch support facilities are desired:

a. X-Ray Telescope Support Laboratory with better than 10,000 class cleanliness and thermal control rooms variable from room temperature (293° K) to 273° K, holding temperature constant within ±1° K.

b. Data Reduction and Ground Control Simulation Facility. Information return, monitoring, processing, and experiment control sequences will be tested with the assembled X-ray stellar astronomy equipment to perform integrated system tests assuring operability of the facility and experiment items.

c. 1.85 km (1 n.mi.) X-ray Test Facility. Nearly parallel beams of X-rays are now in operation or being installed at various institutions for this purpose, but these are inadequate for the optics described here. By nearly parallel we mean a divergence, across the aperture of the telescope, which is small compared to the average grazing angle of the front mirror. For a facility 1.85 km (1 n.mi.) long and a 0.92 m (36 inch) aperture telescope, the divergence would be 5.8×10^{-4} rad (2 arcmin), which is acceptable; for a 91.5 m (300 ft) facility, the divergence would be about 8.8×10^{-3} rad (30 arcmin), which is comparable to the grazing angle. Such a long facility could be utilized to test and align the entire payload since the apparent "direction" of the X-ray source located at the far end would be shifted

Table 1-11. Estimated Schedule for X-Ray Stellar Astronomy Experiment Equipment



(by parallax) by no more than a few arcminutes between instruments. One end of the facility would need to be large enough to accomodate the entire payload; the other end need only accommodate a modest-sized X-ray source. The evacuated tube between the two ends need only be maintained at a high vacuum of $<10^{-4}$ N/m^2 ($<10^{-6}$ torr).

1.9 SAFETY ANALYSIS

The X-ray telescope equipments will have moving mechanisms (interchange equipment) and optical benches capable of trapping the scientist astronaut if activated when he is servicing or calibrating the instrument packages. Safe control schemes will need to be arranged so that remote control positions are carefully monitored or deactivated when local control is desired. Some of the sensor and imaging equipment will require high voltages and will need adjustment or servicing in situ in space.

1.10 AVAILABLE BACKGROUND DATA

a. Proceedings of the Candidate Experiment Program, Astronomy Review Group Meeting, 28 July 1970 at MSFC.

b. Document ASE 2266A, Preliminary Study; Telescopes and Scientific Systems for a High Energy Astronomy Observatory, rev. 26 September 1967.

c. NASA SP-213, a Long Range Program in Space Astronomy, July 1969.

VOLUME II

SECTION 2

ADVANCED STELLAR ASTRONOMY

SECTION 2

ADVANCED STELLAR ASTRONOMY

2.1 GOALS AND OBJECTIVES

Diffraction-limited images from a large telescope in space can provide a significant increase in our knowledge of the spatial structure of astronomical objects and permit the detection of fainter objects than is presently possible from the ground, because of increased angular resolution. It will also allow higher spectral resolution to be achieved more efficiently by instruments employing dispersive optical systems. The advanced stellar astronomy goals in space are:

a. Improved observation of stellar objects in the 10^{-5} to 9×10^{-7} m (10,000 Å to 900 Å) spectral region by imaging, spectrometry, photometry, and polarization measurement.

b. High resolution spectrometry and imaging of planetary bodies.

c. Acquisition of operational information enabling evaluation of design philosophies and operational techniques for candidate manned (or man-controlled) space telescopes. The more immediate goal is to obtain sufficient design information and experience with a typical large (2 to 3 meter, 6.5 to 9.8 ft) telescope that would enable better definition and combination of user, observer, and scientist/astronaut requirements for a National Astronomical Space Observatory telescope.

d. The long term goal of observational astronomy in the short wavelength IR, visible light, and UV portions of the spectrum is to obtain an operational high resolution large (2.54 to 3.05 m, 100 to 120 in.) diameter telescope in space by the early 1980's. Such a telescope would enable maximum state-of-art observational capabilities with minimum limitation from Earth atmosphere, sky brightness, cloud obscuration, and atmospheric varying refraction effects.

2.2 PHYSICAL DESCRIPTION

The facility equipment for the advanced stellar astronomy functional program element (FPE) will consist of two candidate telescopes, one of which will be operated experimentally in space prior to establishment of a more permanent telescope for National Astronomy Space Observations (NASO). This first telescope may be either two or three meters in diameter at the aperture and will be arranged to accommodate various optical technology experiments as well as engaging in scientific stellar observations. All telescope options considered for advanced stellar astronomy will allow for attachment or retrofit of various instruments at one of the foci or beam split optical points to enable accommodation of instruments for a number of investigators. The telescopes will be capable of being monitored and remotely controlled from the ground as well as from a nearby Space Station or a logistics (Shuttle) service vehicle. The operational life of a large space telescope, maintainable by man, will have a design goal of 10

years. Maintenance and updating operations will include replacement of expendables, experimental instruments, alignment equipment, and calibration equipment, as well as remote control and monitoring devices.

Table 2-1 shows major facility items and experimental instruments versus the kinds of experiments expected to be accomplished.

Facility operational and support functions are allocated as follows: The telescope will accomplish very fine tracking of guide stars by means of auxiliary tracker units obtaining light signals via the primary and secondary mirrors. The guide star trackers of the telescope will furnish steering signals to the supporting (carrier) vehicle to enable pointing the telescope axis with respect to the guide (reference) stars. The supporting vehicle carrying the telescope will provide power, data handling, thrust control, gross pointing for acquisition, and reference star tracking for locating guide stars for the large telescope to lock-on. Commands for pointing and operating the support vehicle as well as for the individual telescope adjustments and functions will be received, decoded, and routed to the appropriate unit by the supporting vehicle.

Figure 2-1 shows a typical large telescope configuration with retracted dimensions. When extended for operation, the two-meter telescope is 13.07 m (514 in.) long; the three-meter telescope is 17.7 m (696 in.) long.

Collector parameters for the two telescopes are listed in Table 2-2.

Weights for the telescopes, experiment instrumentation, and accessories are presented in Table 2-3.

a. Three-Meter Advanced Stellar Astronomy Telescope. The telescope is a Cassegrain collector with a primary mirror of 3-m aperture and 12-m focal length, and a secondary mirror which provides the 3.75-power magnification for an effective focal length of 45 m. A field of view of 1.17×10^{-3} to 8.74×10^{-3} rad (4 to 30 arcmin) is desired by various investigators. Since a field of these dimensions would be helpful in locating suitable guide stars as well as enabling location between reference stars, a Ritchey-Chretien figuring of the primary and secondary reflectors is recommended in preference to the classical Cassegrainian (paraboloid-hyperboloid) type because of its wider aberration-free field of view. Electronic imaging, spectrographic, photometric, and polarization measuring instruments, which may be interchanged, replaced and updated as required, will be located on the instrument mounting platen of the telescope. Two instrument groups will be included, one for field image monitoring and the other for spectroscopy.

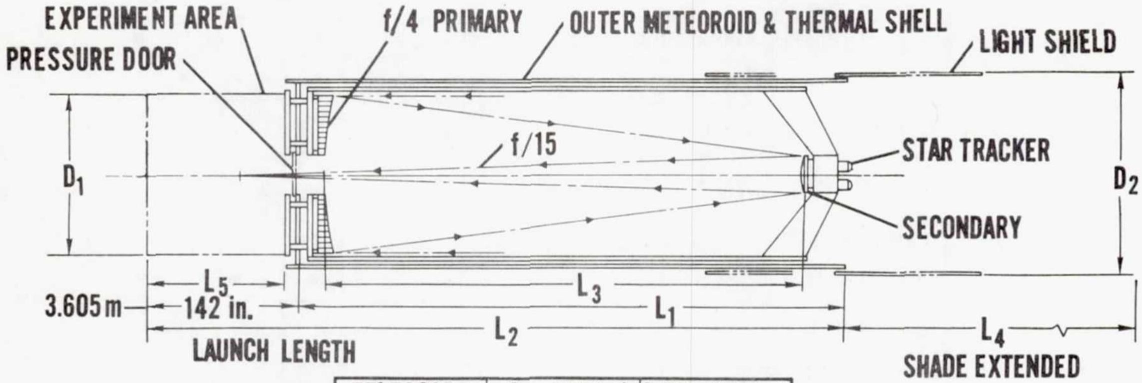
Table 2-1. Facility and Special (Experiment) Equipment Versus Experiment

EXPERIMENT CLASS	FACILITY ITEMS A: 2 METER DIAMETER APERTURE TELESCOPE (OPTION 1)	B: 3 METER DIAMETER APERTURE TELESCOPE (OPTION 2)	C: ALIGNMENT AND CALIBRATION INSTRUMENTATION	D: OBSERVATION/MEASUREMENT/ POINTING CONTROL AND OUTPUT INFORMATION PROCESSING COMPUTER*	KINDS OF SPECIAL EQUIPMENT 1: AUTO FOCUS EQUIPMENT	2: GUIDE STAR TRACKERS (2)	3: OUTER FIELD CORRECTOR	4: IMAGE MOVER	5: F/50 IMAGING MICROSCOPE	6: F/60 IMAGING MICROSCOPE	7: 1.5 INCH ELECTRONIC IMAGING CAMERA	8: 6 INCH DIA ELECTRONIC IMAGING CAMERA	9: 25.4 × 25.4 MM FILM PLATE HOLDER	10: 254 × 254 MM PLATE CAMERA	11: SPECTROPHOTOMETER	12: MODIFIED ECHELLE SPECTROMETER	13: ROWLAND CIRCLE SPECTROMETER	14: IR FOURIER SPECTROMETER	15: POLARIMETER	16: OPTIONAL STAR TRACKER/INERTIAL REF. UNIT
STELLAR OBSERVATION																				
FOCUS AND ALIGNMENT	o	●	●	o	●	●	●	●	-	●	-	●	-	●	●	●	●	●	o	o
GUIDE STAR ACQUISITION	o	●		o	o	●	●	●	-	-	-	-	-	-	-	-	-	-	-	o
OBSERVED OBJECT ACQUISITION AND LOCATION	o	●	o	●	●	●	●	●	-	●	-	●	-	●	-	-	-	-	-	o
HIGH RESOLUTION ELECTRONIC IMAGING	o	●		o	●	●	o	●	-	●	-	●	-	●	-	-	-	-	-	o
BACKUP FILM IMAGING	o	●		-	●	●	●	●	-	●	-	o	-	●	-	-	-	-	-	o
SPECTROPHOTOMETRY	o	●		o	●	●	●	●	-	-	-	-	-	-	●	-	-	-	-	o
SPECTROSCOPY	o	●		o	o	o	●	●	-	-	-	-	-	-	-	●	●	●	-	o
POLARIMETRY	o	o		o	o	o	o	-	-	-	-	-	-	-	-	-	-	-	o	o

*Item D Equivalent to be supplied as joint functions of the telescope carrier vehicle, space station (if in loop), and advanced stellar astronomy control station on the ground.

● Preferred Selection

o Optional or Alternative in Place of First Choice or Supporting Vehicle Functions



TELESCOPE	2m (80 in.)		3.05m(120in.)	
DIMENSION	m	in.	m	in.
D_1	3.05	120	3.82	150
D_2	3.25	128	4.27	168
L_1	6.92	272	10.21	402
L_2	10.50	414	13.80	544
L_3	5.78	227	9.01	354
L_4	2.54	100	3.87	152
L_5	3.05	120	3.05	120

Figure 2-1. Typical Large Telescope Configuration Options and Dimensions

Figure 2-1 shows a telescope based on a one-piece primary mirror. Considering manufacturing tolerance and thermal distortions, it may not be feasible to achieve the desired performance with this approach. If so, active optics offer a possible alternative technique for meeting diffraction-limited performance. For the purpose of obtaining adequate spacecraft accommodations for all cases, we shall assume the larger and heavier one-piece primary, as described.

b. Two-Meter Advanced Stellar Astronomy Telescope. The essential components of the 2-m telescope experiments may consist of Cassegrain optics of the Ritchey-Chretien type with a basic system f number of 15 and an electronics imaging f number of 50. The telescope system has a rotatable flat near the focal plane which may be turned to direct optical energy from the primary and secondary mirrors to one of six experiment packages. A seventh experiment package is accessed by flipping the folding optical flat out of the optical path. A generic telescope configuration is given in Figure 2-1, collector parameters in Table 2-2, and weights in Table 2-3.

Table 2-2. Collector and Associated Optics Parameters for Advanced Stellar Astronomy Telescope Options

PARAMETER IDENTIFICATION	THREE METER TELESCOPE PARAMETERS	TWO METER TELESCOPE PARAMETERS
Aperture	3.05 m (120 inches)	2.0 m (78.6 inches)
Primary focal length	12.2 m (480 inches)	8.0 m (314.4 inches)
Total field of view	1.16×10^{-3} radians (4 arcmin) w/o corrector	1.456×10^{-3} radians (5 arcmin) w/o corrector
	8.73×10^{-3} radians (30 arcmin) with corrector	8.73×10^{-3} radians (30 arcmin) with corrector
Angular resolution		
On axis	1.94×10^{-7} radians (0.04 arcsec) at 5,000 Å	2.91×10^{-7} radians (0.06 arcsec) at 5,000 Å
Poorest in field of view	4.85×10^{-7} radians (0.10 arcsec) at 5,000 Å	
Fine Guidance Image Field	1.94×10^{-5} radians (4 arcsec)	1.94×10^{-5} radians (4 arcsec)
Minimum wavelength	9×10^{-2} μm (900 Å)	1080 Å (800 Å)
Maximum wavelength	1 μm (10,000 Å)	1 μm (10,000 Å)
Primary f/No.	f/4	f/4
System f/No.	f/15	f/15

Note: Space stabilization requirements within the 1.94×10^{-5} rad (4 arcsec) field must be determined.

Table 2-3. Estimated Advanced Stellar Astronomy Telescope Weights and Volumes

ITEM	3 METER TELESCOPE				2 METER TELESCOPE				ENVELOPE DIMENSIONS	
	Mass (Weight)		Volume		Mass (Weight)		Volume		3 Meter Teles.	2 Meter Teles.
	kg	(lb)	m^3	ft^3	kg	(lb)	m^3	ft^3	m (ft)	m (ft)
Primary Mirror	1,500	3,300			634	1,400				
Primary Mount	454	1,000			202	450				
Secondary Mirror	317	700			90.6	200				
Secondary Mount	136	300			45.5	100				
Structure (Tube)	1,580	3,500			72.5	1,600				
Light Shield	226	500			90.6	200				
Support Extender	68	150			36.3	80				
Structural Support	226	500			13.6	300				
Support Base	385	850			158	350				
Bulkhead	725	1,600			326	720				
Instrumentation	90.6	200			90.6	200				
Sub-Total (Telescope)	5,700	12,600	146	5,150	2,540	5,600	58.9	2,080	4.3 D × 10.75 L (14 D × 35.3 L)	3.25 D × 7.46 L (10.7 D × 24.5 L)
Experiments**	544	1,200	34	1,200*	452	1,000	15.3	542	3.81 D × 3.05 L (12.5 D × 10 L)	2.54 D × 3.05 L (8.33 D × 10 L)
FPE Total	6,252	13,800	180	6,350	2,987	6,600	74.4	2,622	4.3 D × 13.8 L (14 D × 45.2 L)	3.25 D × 10.5 L (10.7 D × 34.4 L)

*Accommodates 6 ea. 5 m^3 (180 cu ft) experiments and one 2.83 m^3 (100 cu ft) experiment leaving 0.71 m^3 (25 cu ft) for the light path switch (flip) mirror.
**Partial complement of instruments only.

For diffraction-limited imaging, it is essential that the telescope field be stabilized by closed-loop guiding on two guide stars within the telescope field. The diffraction-limited image field of 1.16×10^{-3} rad (4 arcmin) in diameter is substantially larger than can be handled with present imaging tubes (better ones are under development), but is too small by a factor of seven if two guide stars of sufficient brightness are needed in the field of view when the telescope is oriented toward galactic poles. A corrector near the focal plane may be added to the telescope to yield a well-corrected 8.73×10^{-3} radians (30 arcmin) guidance field. A hole through the refractive corrector elements passes the small useful central field of the telescope so that the total spectrum of 1 μm (10,000 Å) to 0.1 μm (1000 Å) is available in this field.

2.3 EXPERIMENT REQUIREMENTS SUMMARY

The requirements of each group of experiments are summarized in Table 2-4. Technology and observation experiments have the same performance requirements.

2.4 EXPERIMENT PROGRAM

The advanced stellar astronomy experiments are divided into two groups of experiments: Technology for obtaining information leading to better telescopes, instruments, and operational techniques, and Stellar Observations, which includes all critical processes involved in locating and observing stellar objects. A relatively brief portion of time of the large space telescope will be devoted to the technology experiments. These will basically be limited to verification of proper performance of the telescope prior to systematic stellar observation.

2.4.1 TECHNOLOGY EXPERIMENTS

2.4.1.1 Technical Objectives. The objective of the technology evaluation experiment is to evaluate the overall and subsystem performance of the telescope, including stabilization to 5×10^{-8} radians (0.01 arcsec). Fine-pointing capabilities of this magnitude are necessary for the large-telescope astronomy projects and as a test bed for advanced guidance components testing. Attainment of this overall objective has the following major elements:

a. Determination of the pointing accuracy and threshold of attitude sensors on the support module and telescope.

b. Checkout of guide star acquisition technique.

c. Determination of the stability provided by a low-friction momentum exchange actuation device mounted integral to the support vehicle.

Table 2-4. Advanced Stellar Astronomy Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
2.4.2 Stellar Observation Experiments	6252 (13,800) or 2987 (6600)	780 (6350) Including 350 cu ft Access	4.3 D × 13.8 L (14 D × 45.2 L) Section outside of supporting vehicle bulkhead attachment sta. is: 4.3 D × 10.2 L (14 D × 33.5 L) for 3m telescope	Average: 565 Peak: 715 Standby: 265	Astronomer/ Astrophysicist Optical Scientist Optical Technician	Temp Limits: 294 ± 1°K desired Ops Atmosphere: 0 to 10^5 N/m^2 (0-15 psi) 1.33×10^{-4} ($<10^{-6}$ torr) pref. Gravity Level: $< 10^{-4}$ g, during ops Radiation Sensitivity: < 1 millirad/hr	Setup: 15 Ops Cycle: 14.6;1-4 per exp run Maintenance: 6 per 180 D	Picture Elements Per Image: 1.6×10^7 Images/Sec: 1.15×10^{-5} to 10 Digital Picture Data: 1.12×10^8 bits per image Non Imaging Data: Command: 10^3 bps Science/Exps: 10^3 bps Housekeeping: 2×10^3 bps	Pointing Accuracy: 5×10^{-6} rad (1 arcsec) pref. 5×10^{-5} rad (10 arcsec) min. Pointing Stability: 2.4×10^{-8} rad (0.005 arcsec/obs time) Max. Slew Rate: Desired: 0.1 rad/ min (6°/min) Accept.: 0.03 rad/ min (2°/min) Min. Slew Rate: 2.4×10^{-8} rad/sec (<0.005 arcsec/sec) Pointing Hold Time: 360 to 14,400 sec/ obs period. Avg.= 2400 sec. Extension to 86,400 sec desired	Desired Incl: (28° to 55°) Acceptable Incl: > 0° Desired Alt: 670 to 830 km (360 to 450 n.mi.) Acceptable Alt: 460 to 670 km (250 to 360) n.mi.) (These numbers not critical to Astronomy Mission)	Free Flying Minimum Vibration Minimum Contamination Remote Monitoring and Control Scheduled Manned Maintenance once per 180D Improved Exp. Instruments may be substituted in space On axis pointing most desirable

NOTE: Data subject to further definition as systems and interfaces become better defined.

2.4.1.2 Description

a. Subsystem Performance Evaluation. The objective is information in the areas critical to the telescope performance, i.e., optical train, data handling, fractional arcsec altitude control, telescope suspension system, thermal control, etc. The primary mirror will probably be of passive monolithic construction, with possibly partial active control as a secondary option. As experiments proceed, additional equipment will be brought up to carry out alternative configuration experiments. Particularly, experiments will be performed to monitor environmental parameters and determine by test the performance of major telescope subsystems. The technology experiments are open ended, with representative experimental processes only defined, at present. The goal of the continual technology experiments is to gradually obtain a technology information base on systems design and operational techniques to enhance future design of the more advanced National Astronomical Space Observatory facility items.

b. Overall System Evaluation. The module contains its own control system for flying to and from the Space Station or shuttle, and onboard power, thermal control system, data and communication system, guidance sensors, and digital computer for automatic operation of all systems during the fine-pointing experiment. The module design includes sufficient space, power and data capacity for advanced guidance component tests. The module control system employs mass-expulsion for propulsion, but during acquisition and fine-point testing the primary vehicle attitude control system is of the momentum exchange type. It is sized to absorb the cyclical component of momentum but will saturate in the presence of accumulated momentum in the same direction. A momentum dumping system, required to desaturate the momentum actuator, is provided by the support vehicle. The telescope must provide a special fine-point error signal, derived from integral guide star sensors, to the attitude control system.

The ability to point the module to the desired 5×10^{-8} radian (0.01 arcsec) accuracy is highly dependent on the momentum exchange unit threshold characteristics and dumping perturbation torque and frequency.

The experiment module and its associated control system will be initially activated and checked out while docked to the Space Station/Shuttle. While docked, consideration should be given to potential contamination of experiment optics from space station effluents. The Space Station/Shuttle may be required to orient the docked support vehicle to place the telescope optics on selected guide stars.

2.4.1.3 Observation/Measurement Program for Technology Experiments. The following preparation and experiment operations program is expected for technology experiments. Since the technology experiments include in-space development and

comparative tests of optional methods to achieve an effective procedure, preparation and maintenance activities are also shown below. The observations/measurements focus on the following:

a. Measurements of the fine-point stability and accuracy derived from the guide star sensor outputs.

b. Measurement of the fine-point stability and accuracy derived from study of observation images.

c. Comparison of the stability afforded by the basic support vehicle momentum exchange system with the experiment-peculiar system if both are installed.

d. Measurement of the motion recorded by the support vehicle stellar-inertial reference to obtain data on local flexure induced by the orbit thermal environment and support vehicle flexibility.

e. Checkout of the guide star acquisition technique at various levels of guide star sensor field-of-views.

The time needed for initial in-space preparation and checkout while attached to the space station is estimated to be 8 hours. Guide star acquisition checkout time is estimated at 0.2 hour per trial with 10 trials expected. Accumulation of data for fine-pointing evaluation is expected to consume four hours per observation. At least two long-term observations will be required. An overall period of execution for this experiment is 48 hours.

Data from the experiment will be telemetered to the Space Station or Shuttle for subsequent transmittal to earth.

2.4.1.4 Technology Experiment Interface, Support, and Performance Requirements. The technology experiment interface, support, and performance requirements are presented in column's a, b, c, d and e of Table 2-5.

The crew will be required to energize and checkout the experiment while it is docked to the Space Station/Shuttle. After a complete checkout, the crew will remotely fly the module to a remote location where the stabilization experiment will be conducted. The crew must also ensure that the telemetered data is received and retransmitted to earth.

2.4.1.5 Potential Role of Man. For technology experiments, astronaut/optical scientists and technician will test the large telescope and associated experiment equipment to give conclusive information as to performance of the telescope and subsystems. Although actual test operations are accomplished unmanned in a free-flying mode, in-space checkout, including adjustment of automatic and remote control alignment and focus devices into or near the middle of their control ranges, requires a two-man team.

Table 2-5. Stellar Observation Experiments Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Focus and Alignment	b. Guide Star Acquisition	c. Observed Stellar Object Acquisition and Location	d. High Resolution Electronic Imaging	e. Backup Film Imaging	f. Spectrophotometry	g. Spectroscopy	h. Polarimetry	MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	3 or 2 meter dia. Telescope Alignment and Calibration Equip. Control Info. Process Computer Spec. Equipment 1,2,3,4,6,8,9, 10,11,12,13,14, 15,16	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,21 plus Optional 17,18,19, 16	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,6,8,10, 16	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,6,8	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,6,8,10, 16	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,11, 21 plus 19 or 16	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,4,21 plus one of 12,13, or 14, 16, 17	3 or 2 meter dia. Telescope Control + Info. Process Computer Spec. Equipment* 1,2,3,15, 16	3 or 2 meter dia. Telescope Alignment and Calibration Equip. Control + Info. Process Services Spec. Equipment* 1-16	3 or 2 meter dia. Telescope Alignment and Calibration Equip. Control + Info. Process Computer Spec. Equipment* 1,2,3,4,6,8,10, 11,12,13,14,15, 16
Launch Mass, kg (Weight, lb)									2987 (6600)	6252 (13800)
Logistics Support:										
Consumables, kg/180D (If (lb/180D) Film)	0.53 (1.2)	0.53 (1.2)	0.44 (0.97)	1.8 (3.9)	213 (470)	-	2.4 (5.3)	5.4 (1.2)	220 (484)	2200 (4840)
Spares, kg/180D (lb/180D)	13.6 (30)	-	-	-	-	-	-	-	13.6 (30)	13.6 (30)
Crew Support:										
Initial Setup, Manhours/180D	15	-	-	-	-	-	-	-	15	15
Periodic Serv. & Maint., Manhours/180D	6	-	-	-	-	-	-	-	6	6
Operation, Remote Control, Manhours/Observation Cycle	0.7	0.1	0.1	Up to 0.07	Up to 4	Up to 4	0.7 + 4.6	Up to 0.7	3.7 to 14.9	14.9 max. cycle for all instruments
Electric Power: (Body point only, computer part of vehicle) †										
Peak Load, Watts	715	415	715	245	95	565	125	150	715	715
Average Load, Watts	265	265	265	85	65	565	117	150	565	565
Standby Load, Watts	265	265	265	85	65	265	110	150	265	265
Environmental Control:										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	296 ±10	296 ± 10	296 ± 10	296 ±10	296 ±10	296 ± 10	296 ± 10	296 ±10	296 ±10	296 ± 10
Temp. Range, Ops., °K	294 ±1	294 ± 1	294 ± 1	294 ±1	294 ±1	294 ± 1	294 ± 1	294 ±1	294 ±1	294 ± 1
Max. Temp. Difference, °K	2**	2**	2**	2**	2**	2**	2**	2**	2**	2**
Relative Humidity, % ***	0	0	0	0	0	0	0	0	0	0
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 (0-15)	0 to 10^5, 1.33×10^{-4} (0-15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0-15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0-15, $\leq 10^{-6}$ torr)	0 to 10^5, 1.33×10^{-4} (0-15, $\leq 10^{-6}$ torr)	0 to 10^5, 1.33×10^{-4} (0-15, $\leq 10^{-6}$ torr)	0 to 10^5, 1.33×10^{-4} (0-15, $\leq 10^{-6}$ torr)	0 to 10^5, 1.33×10^{-4} (0-15, $\leq 10^{-6}$ torr)	0 to 10^5, 1.33×10^{-4} (0-15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0-15, $< 10^{-6}$ torr)
Cleanliness Class	Pref. 10,000 Max. 100,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	100,000	10,000
Gravity Level, Max. g	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$
Radiation Sensitivity, millirad/hr	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	≤ 1	< 1
Contamination Sensitivity	slight	slight	moderate	moderate	moderate	moderate	moderate	moderate	slight to moderate	out of contamination cloud; protected

*See Table 2-1 for equipment identification

**For total telescope but primary mirror $\Delta T \leq 0.2°K$; instruments controlled to $\Delta T < 0.1°K$

*** When operating; humidity may go to about 10% when serviced.

†Plus 1200 W for 3 meter telescope and 500 W for 2 meter telescope if RAM subsystem excess heat not utilized

Table 2-5. Stellar Observation Experiments Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS \ EXPERIMENT	a. Focus and Alignment	b. Guide Star Acquisition	c. Observed Stellar Object Acquisition and Location	d. High Resolution Electronic Imaging	e. Backup Film Imaging	f. Spectrophotometry	g. Spectroscopy	h. Polarimetry	MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55	28 to 55
Acceptable Inclination, deg	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	
Desired Altitude, km (n.mi.)	670 to 830 (360 to 450)	670 to 830 (360 to 450)	670 to 830 (360 to 450)	>670 to 830 (360 to 450)	670 to 830 (360 to 450)	670 to 830 (360 to 450)	670 to 830 (360 to 450)	670 to 830 (360 to 450)		670 to 830 (360 to 450)
Acceptable Altitude, km (n.mi.)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)	460 to 670 (250 to 360)
Orientation:										
Observed Object Location	Internal lighted patterns + bright star	2 stars, ≥ 90° from center of earth or sun	Object ≥ 90° from center of earth or sun	Object ≥ 90° from center of earth or sun	Equiv. point source ≥ 90° from center of earth or sun	Equiv. point source ≥ 90° from center of earth or sun	Equiv. point source ≥ 90° from center of earth or sun	Equiv. point source ≥ 90° from center of earth or sun	Stellar objects and guide stars	Stellar objects and guide stars
Observed Object Brightness, mag., m_v	Variable -2.5 to 24	> 8	> 27	> 27	> 25	> 24	> 20	> 18	-2.5 to 29	-2.5 to 29
Observation Field of View	2×10^{-4} rad (40 arcsec) selected from 1.16×10^{-3} rad (4 arcmin)	2×10^{-5} rad (4 arcsec) selected from 8.7×10^{-3} rad (30 arcmin)	2×10^{-4} rad (40 arcsec) selected from 1.16×10^{-3} rad (4 arcmin)	8×10^{-4} rad (160 arcsec) selected from 1.16×10^{-3} rad (4 arcmin)	1.16×10^{-3} rad (240 arcsec)	2×10^{-5} rad (down to 4 arcsec)	2×10^{-5} rad (down to 4 arcsec)	2×10^{-5} rad (down to 4 arcsec)	2×10^{-5} to 1.16×10^{-3} rad (4 to 240 arcsec)	2×10^{-5} to 1.16×10^{-3} rad (4 to 240 arcsec)
Pointing Accuracy, rad (arcsec)	5×10^{-6} (1)	5×10^{-6} (1) for acq.	Pre: 5×10^{-6} (1) Acc: 5×10^{-5} (10)	Pre: 5×10^{-6} (1) Acc: 5×10^{-5} (10)	Pre: 5×10^{-6} (1) Acc: 5×10^{-5} (10)	Pre: 5×10^{-6} (1) Acc: 5×10^{-5} (10)	5×10^{-6} On axis to > (1)	5×10^{-6} On axis to < (1)	5×10^{-5} (10)	5×10^{-6} (1)
Pointing Stability, rad/obs time (arcsec/obs time)	5×10^{-9} (<0.005)	5×10^{-9} (~0.005)	5×10^{-9} (0.005)	Pre: 5×10^{-9} (0.005) Acc: 8×10^{-9} (0.008)	Pre: 5×10^{-9} (0.005) Acc: 8×10^{-9} (0.008)	Pre: 5×10^{-9} (0.005) Acc: 8×10^{-9} (0.008)	5×10^{-9} (0.005)	5×10^{-9} (0.005)	8×10^{-9} (0.008)	5×10^{-9} (0.005)
Slew Rate, max., rad/sec (arcsec/sec)	-	Des: 1.75×10^{-3} (360) Acc: 3.5×10^{-4} (72)	Des: 1.75×10^{-3} (360) Acc: 3.5×10^{-4} (72)	-	-	-	-	-	3.5×10^{-4} (72)	1.75×10^{-3} (360)
Slew Rate, min., rad/sec (arcsec/sec)	-	5×10^{-6} (<0.005)	5×10^{-6} (< 0.005)	5×10^{-6} (< 0.005)	5×10^{-6} (<0.005)	-	5×10^{-6} (0.005)	5×10^{-6} (<0.005)	5×10^{-6} (0.005)	5×10^{-6} (0.005)
Pointing Hold Time, sec	2520	360	~ 600	Up to 2400	Up to 14,400 Extension to 86,400 desired	Up to 14,400	Up to 14,400	Up to 14,400	360 to 14,400	360 to 14,400 Extension to 86,400
Data Requirements/Observation Cycle:										
Imaging Data:										
Desired Resolution (spatial or spectral)	2×10^{-7} rad (0.04 arcsec)	Des: 2×10^{-8} rad (0.004 arcsec) Acc: 2.4×10^{-8} rad (0.005 arcsec)	Des: 5×10^{-8} rad (0.01 arcsec) Acc: 2×10^{-7} rad (0.04 arcsec)	Des: 5×10^{-8} rad (0.01 arcsec) Acc: 2×10^{-7} rad (0.04 arcsec)	2×10^{-7} rad (0.04 arcsec) Equipment: 5×10^{-8} rad (0.01 arcsec) Film: 1.2×10^{-7} rad (0.025 arcsec)	-	2×10^{-11} to 5×10^{-3} m (0.2 to 0.005 Å)	1 pair equiv.	2×10^{-7} rad (0.04 arcsec) 2×10^{-11} m	2×10^{-11} m to 5×10^{-13} m (0.2 to 0.005 Å) 2×10^{-8} rad (0.004) to 2×10^{-7} rad (0.04 arcsec)
Equiv. Image Format Size, mm	2×10^{-4} by 2×10^{-4} rad (40x40 arcsec) 25.4 x 25.4	Variable down to 2×10^{-5} by 2×10^{-5} rad (4x4 arcsec) 25.4 x 25.4	2×10^{-4} by 2×10^{-4} rad (40x40 arcsec) 25.4 x 25.4	Des: $(7.75 \times 10^{-4})^2$ rad (160x160 arcsec) 100 x 100 Acc: (40x40 arcsec) 25.4 x 25.4	Des: 1.16×10^{-3} by 1.16×10^{-3} rad (240x240 arcsec) 240 x 240mm	-	Des: 100x100 Acc: 25.4x25.4	25.4 x 25.4	25.4 x 25.4	100 x 100
Picture Elements/Image	$1{,}000 \times 1{,}000 = 10^6$	$10^3 \times 10^3 = 10^6$	$10^3 \times 10^3 = 10^6$	Des: $4{,}000 \times 4{,}000 = 1.6 \times 10^7$ Acc: $1{,}000 \times 1{,}000 = 10^6$	Des: $10^4 \times 10^4 = 10^8$ on film	-	Des: 10^5/image Acc: 12500/image	$10^3 \times 10^3 = 10^6$	$\sim 10^6$	1.6×10^7
Images/Data Set**	(2)	(2)	1	1	1	-	5 equiv	2 pairs	-	16**
Images/Second	1	1	0.1 to 1.66×10^{-3}	1 to 4.64×10^{-5}	8×10^{-5} to 1.16×10^{-5}	-	1 to 4.64×10^{-5}	1 to 4.64×10^{-5}	4.64×10^{-5}	1.16×10^{-5} to 1
Photometric Resolution, %, bits	1,7	1,7	1,7	1,7	1,7	10^{-4}	1,7	1,7	1,7	1,7
Equiv. Analog Data, MHz	11	11	11	Desired: 176 Acceptable: 11	Desired: 1100 Acceptable: 70.9	-	-	-	11 if used for monitoring field of view	11 if used for monitoring field of view
Equiv. Digital Data, bits/image	(7×10^6)	7×10^6	7×10^6	Des: 1.12×10^8 Acc: 7×10^6	Des: (1.12×10^8) Acc: (7×10^6)	-	7×10^5	-	7×10^6	1.12×10^8
Non-Imaging Data: Command Data, bps	$\le 10^3$	$\le 10^3$	$\le 10^3$	$\le 10^3$	$< 10^3$	$< 10^3$	$\le 10^3$	$< 10^3$	10^2 to 10^3	$\le 10^3$
Science/Exp. Data, bps	$\le 10^6$	-	-	-	-	-	-	-	-	$\le 10^6$
Housekeeping Data, bps	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3	2×10^3
Special Requirements:										
Updating Cycle, Years	1	1	1	1	2	1	1	2	1 to 2	1 to 2
Mass, kg/year	11.3	22.7	22.7	11.3	11.3	22.7 to 91	22.7 to 91	45.5	171	307
(Weight, lb/year)	(25)	(50)	(50)	(25)	(25)	(50 to 200)	(50 to 200)	(100)	(375)	(675)
Volume, m^3/year	0.09	0.07	0.07	0.57	0.085	0.07 to 0.4	0.07 to 0.4	0.23	0.69	1.3
(ft^3/year)	(3.3)	(2.5)	(2.5)	(2)	(3)	(2.5 to 14)	(2.5 to 14)	(8)	(26.3)	(50)

*Up to 2.5 arcmin with camera direct cassagrain focus

** 2 Data Sets per 24 hours

2.4.1.6 Available Background Data. Engineering Report 9800, Large Telescope Experiment Program, Contract NAS8-21497, 24 April 1970, Perkin Elmer, Norwalk, Conn.

2.4.2 STELLAR OBSERVATION EXPERIMENTS

2.4.2.1 Scientific Objectives. Stellar Observation experiment objectives are to observe discrete and extended stellar objects in the 9×10^{-8} to 10^{-6} m (900Å - 10,000Å) spectral region using imaging, spectrographic, photometric, and polarimetry techniques. The lower wavelength may not be achievable but is a design goal.

2.4.2.2 Description. The experiment packages located in seven operating positions at or near the large-telescope focal plane can be exchanged to accommodate new experiments conceived during the life of the telescope. The following experiments are representative:

a. Focus and Alignment. Focus and alignment is listed as an experiment since the process involves preliminary checkout of the optical paths for the seven key experiment packages to enable a quick observation cycle. The large telescopes utilize in-flight alignment detection and correction capability periodically monitored and remotely controlled by man at a Space Station or ground control center. Seven optical paths are checked and corrected about once per 24 to 30 hours, which is the maximum cycle expected for utilizing all the sensors on a single stellar source. A built-in set of alignment and calibration equipment will be utilized, requiring about 0.1 hour to semiautomatically proceed with checks and corrections for each optical path or channel. The adjustments will include primary mirror tilt adjustment, secondary mirror alignment, primary lateral alignment, longitudinal focus alignment, and alignment and focus of each optical train leading to an instrument.

b. Guide Star Acquisition. With all telescope and instrument optical paths aligned and focused, the next step is guide star acquisition using both the carrier (supporting) vehicle body pointing and guide star trackers. The supporting vehicle star trackers (possibly pitch, yaw, and roll reference) will be directed toward known acquisition reference stars of about sixth magnitude or brighter. These reference star trackers provide data to enable the body of the telescope to be slewed to the desired direction (i.e., galactic coordinates). Two stars brighter than 12th magnitude (symmetrically located with respect to desired observation angle if possible) will be selected in the 8.8×10^{-3} rad (30 arcmin) field of view of the large telescope. Then guide star trackers are locked on to each selected star one at a time. An image mover technique is used to shift each guide star image from an arbitrary position to a final position to give best guiding. The field is then stopped down to approximately 1.9×10^{-5} rad (4 arcsec) about each selected guide star to avoid interference from adjacent stars (poor

tracking S/N). The error signals generated by the guide star tracker sensors internal to the large telescope will then control body pointing with respect to the guide stars to get the telescope axis on the line of sight to the stellar object to be observed. Within limits of the linear field of view near the telescope axis, an image mover on a transfer lens system may also be used to obtain an optimum relationship of the telescope optical axis with respect to the desired line of sight. Since a rotatable flat is used near the focal plane to optically link the telescope optical axis (and beam) to one of the selected experiment packages, guide star tracking may need to be accomplished from each experiment package.

c. Observed Stellar Object Acquisition and Location. Where the object to be observed is near the telescope limiting magnitude in brightness, difficulty may be experienced in acquisition and location of the object due to the long integration time necessary before enough photons are received to register the image. If imperfect location data exists on the source, the problem of acquiring the object within a limited 1.9×10^{-4} rad (40 arcsec) field of view may be quite large. The narrowing of the effective field of view in order to accomplish electronic imaging to maximum angular resolution has brought about the stellar object acquisition and location problem. With computer-programmed search techniques to systematically observe the region around the desired line of sight, the near-limiting-magnitude object or nebula is likely to be located in a reasonable amount of time and be centered in the electronic imaging field by image mover or transfer lens techniques.

For the brighter, more precisely cataloged sources, there will be a little problem in centering the effective electronic imaging field of view along the telescope axis and orienting the telescope body to look directly at the observed object. However, for each telescope the procedure or modus operandi needs to be developed for the different brightness stars and other stellar objects versus the accuracy of previous (if any) cataloging and brightness. The guide star (reference star) trackers locked-on to the nearest stars on two sides of a desired observation region offer a stable set of angular references to enable desired object detection, acquisition, and location. Where possible, for brighter sources, an additional fine-guidance sensor is recommended to be included in each of seven instrument packages to make sure guiding is accomplished for the same field that includes the object star observed.

d. High Resolution Electronic Imaging. High resolution electronic imaging utilizes the aligned optics, calibrated photometric sensitivity, guide star references, stellar object location, and acquisition functions to enable successful preparation for obtaining a high resolution image.

An imaging microscope (f/50 to f/60) is used to relay the central, all-reflective image of the telescope to the sensing surface of an electronic imaging tube. Two

options have been considered in imaging tubes:* (a) a 15.2-cm (6-in.) imaging tube with a 100 x 100 mm linear image surface (40 line pairs per mm) giving 4000 x 4000 picture elements over a 1.9×10^{-4} by 1.9×10^{-4} rad (40 arcsec x 40 arcsec) field and, (b) a 4.1-cm (1.6-in.) diameter imaging tube with a 25.4 x 25.4 mm linear image surface, giving about 1000 x 1000 picture elements per 40 arcsec x 40 arcsec field. The (a) option gives some margin for tube degradation as well as allowing telescope optics rather than the imaging tube to limit resolution. In fact, the effective field may be increased to 7.8×10^{-4} by 7.8×10^{-4} rad (160 arcsec by 160 arcsec) and still achieve 1.9×10^{-8} rad (0.04 arcsec) resolution. Figure 2-2 outlines a typical electronic imaging camera package.

e. Backup Film Imaging. The ability of a photographic plate to record simultaneously a large number of objects makes photography an efficient method for gathering high resolution data on a large number of stars in a limited field. Film plate holders are provided at the input face of each image tube in the large optical telescope assembly to enable obtaining hard copy calibration data and to provide a comparison reference for calibration of imaging tubes. A remotely controllable plate-magazine type camera is also arranged to operate at the f/15 focus with a field of view of 1.2×10^{-3} rad (240 arcsec). The remotely controllable plate camera can be used as backup for the electronic imaging camera. See Figure 2-2 for the plate camera package.

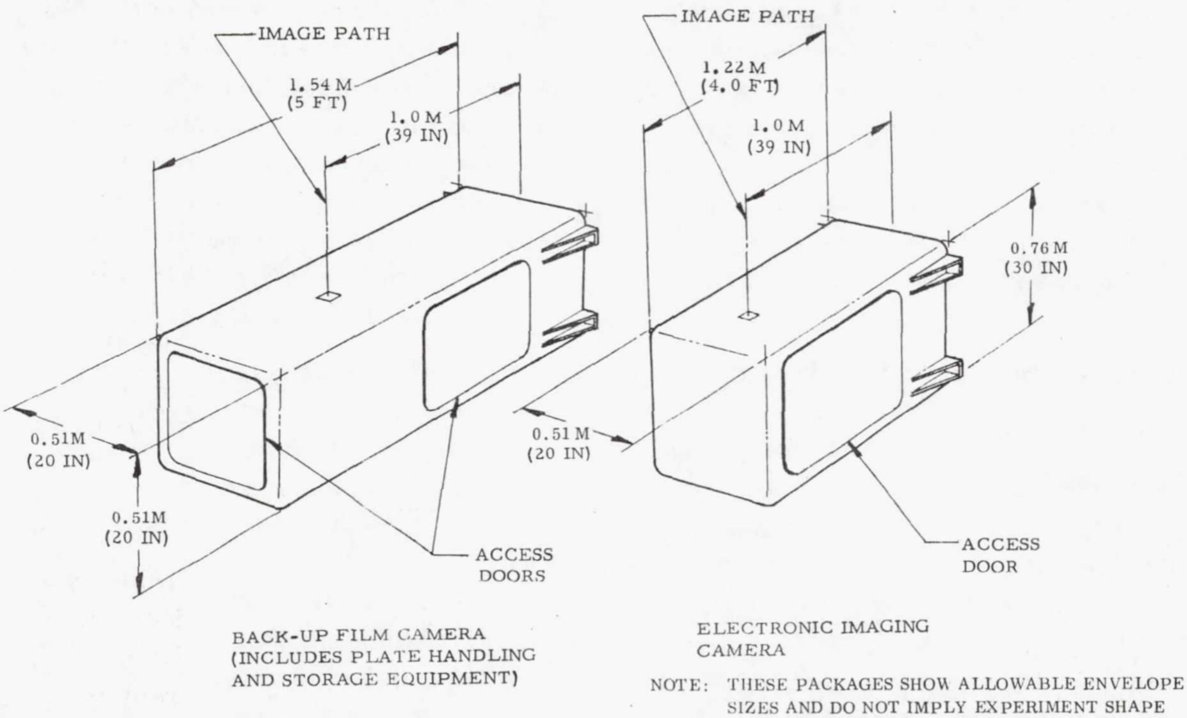


Figure 2-2. Electronic Imaging and Back-up Film Cameras

*If imaging tubes of this capability are not available at the time the telescope is initially launched, they may be added later. The design lifetime of the telescope is 10 years, and it is anticipated that we will have many updated sensors during this period.

f. <u>Spectrophotometry</u>. Spectrophotometry will be accomplished by a multichannel spectrometer (spectrophotometer) to be used on stars of brightness as low as magnitude 22 in the blue and yellow ranges. The spectrophotometer covers the spectrum from 10^{-6} to 3.2×10^{-7} m (10,000 Å to 3200 Å). The instrument will permit bandpasses of 2×10^{-10} to 1.6×10^{-8} m (2 Å to 160 Å) to be used with each photometric detector (photomultiplier). Each of the multiple channels will feed into two seven-digit counters that can accumulate the counts for star plus sky and sky alone. In space, the brightness background will be many times less than possible from sites on earth, so that photometric accuracy in space can be quite high indeed. See Figure 2-3 for spectrophotometer package envelope limiting dimensions.

g. <u>Spectroscopy</u>

1. <u>Low Resolution Spectroscopy</u>. A Rowland circle spectrometer is used in the far ultraviolet region from 8×10^{-8} to 3.2×10^{-7} m (800 Å to 3200 Å) with about 2×10^{-11} m (0.2 Å) resolution. Figure 2-3 shows a typical envelope. Internal guide-star pointing accessories center the telescope on the stellar object to be observed. Rowland spectrometer envelope dimensions may also be seen in Figure 2-3.

2. <u>High Resolution Spectroscopy</u>. A high resolution spectrometer capable of a resolving power of at least 100,000, or about 5×10^{-12} m at a wavelength

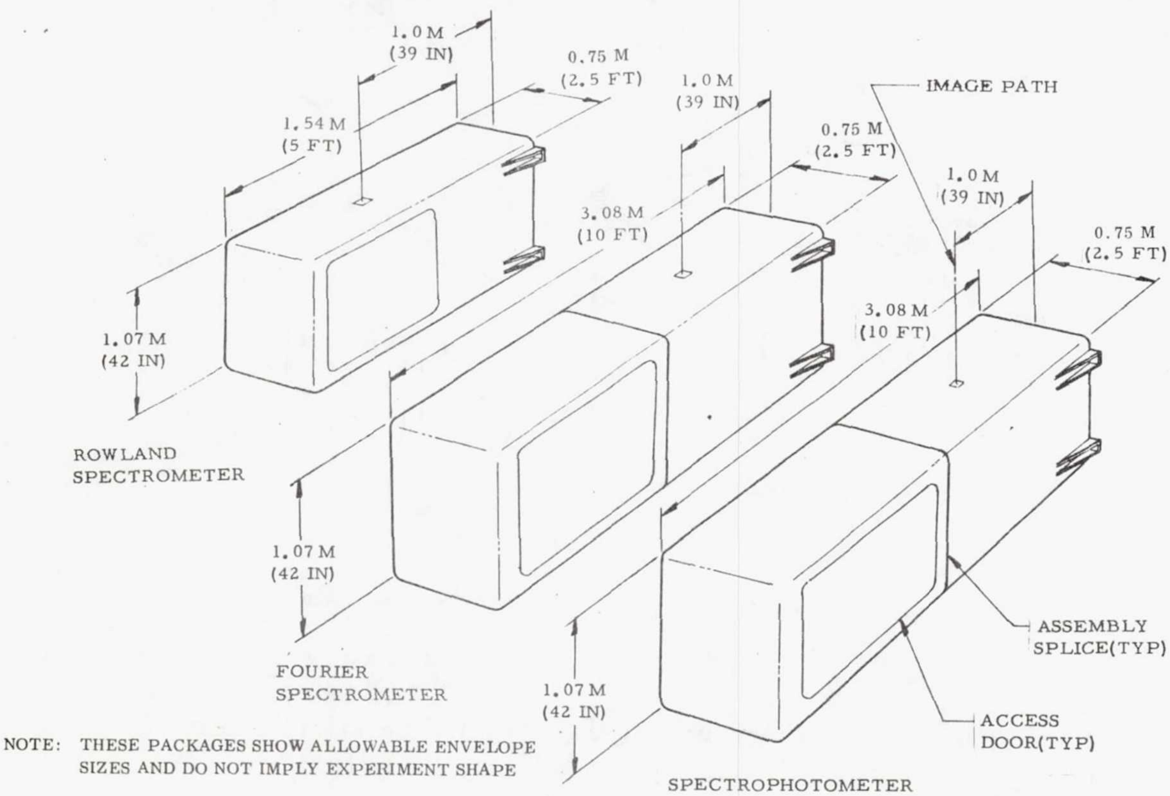


Figure 2-3. Rowland and Fourier Spectrometer and Spectrophotometer Typical Package Envelopes

of 5×10^{-7} m (0.05 Å @ 5000 Å) in the spectrum from about 3.6×10^{-7} to 8×10^{-7} m (3600 Å to 8000 Å) has been considered if enough space is available behind the primary, accessible by one of the telescope output light paths. An interferometer type of spectrometer will be used to make efficient use of incident energy at the longer wavelengths. Detectors are arranged to gather information at a higher rate than that achievable with a single detector, single pass band spectrometer where only one narrow wavelength is available at one time. Possible sharing of equipment by the high resolution Fourier transform spectrometer with the spectrophotometer is being considered. The maximum envelope for a Fourier spectrophotometer package is shown in Figure 2-3.

3. Echelle Spectrometry. A modified echelle spectrometer with both imaging and high dispersion spectrographic capabilities will be used to cover the spectrum from 8×10^{-8} to 3×10^{-7} m (800 Å to 3000 Å). A multiple-element echelle spectrometer envelope with maximum dimensions expected is shown in Figure 2-4. The echelle arrangement produces spectral strips folded like lines of type on a printed page, permitting a large spectral band to be integrated and read out on one or more image tubes in about the same time as required for a single line with a normal monochronometer. Only reflective components are used to enable full coverage of the desired spectral band.

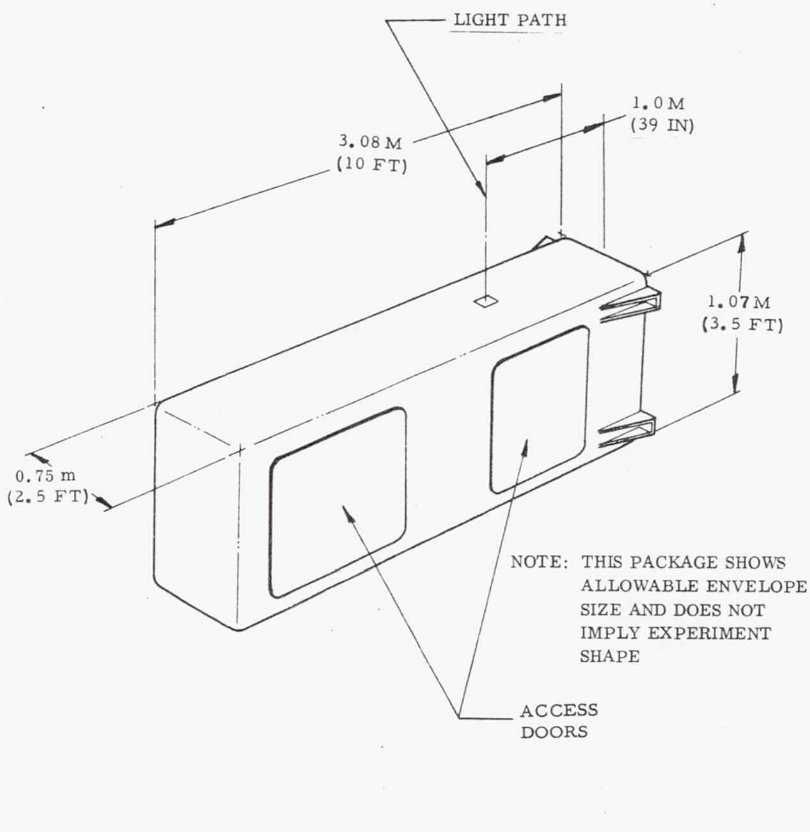


Figure 2-4. Typical Echelle Spectrometer Package Envelope

A 3.8 cm (1.5-in.) diameter imaging tube is likely to be used with a 25.4 mm x 25.4 mm active surface. At the 8×10^{-8} to 3×10^{-7} m (800 Å to 3000 Å) end of the spectrum, the effective resolution of the imaging tube is expected to be at least 40 line pairs per mm as a design goal. Hence, with a dispersion of 10^{-10} (1 Å) per mm, effective spectral resolution is 5×10^{-12} m (0.05 Å), at least*. At 2.5×10^{-9} m (25 Å) per strip, 3000 Å - 800 Å = 2200 Å, will require about 88 strips. Since each spectral strip can be about 1 mm in height, a 25.4 x 25.4 mm imaging tube accommodates about 25 strips. Hence, four images are required for the given spectral coverage. The equivalent number of spectral elements per image then is 500 per strip x 25 strips = 12,500 per image, or 44,000 for 88 strips. If a 15.2 cm (6-in.) imaging tube with a 100 x 100 mm format is used, then 100 Å per strip can be accommodated, giving 22 strips for a 2200 Å band and requiring only one image per desired band. If a higher resolution such as 0.005 Å is desired, and a spectral dispersion of 0.1 Å per mm is obtainable with an echelle spectrometer configuration, about 220 spectral strips will be needed; about 50 spectral strips of 1 to 2 mm height may be accommodated per image and 5 images would be required to cover the 2200 Å spectral range discussed. At 2000 spectral elements per strip and 50 strips per image, 100,000 spectral elements may be integrated and recorded per image. The 2200 Å band can be recorded with 4.4×10^5 spectral elements.

Probably the predispersor grating can be turned to enable recording the several images in sequence. Current imaging tubes allow about 40 minutes (to 240 minutes) of integration time to register a faint series of spectral strips from a faint magnitude star.

Four sequential images of 25 each 25 Å spectral strip could then take 2.66 hr. (9600 sec) per source to observe. If a higher resolution spectrometer giving 0.1 Å per mm dispersion with 5 images of 50 strips at 10 Å per strip is used, total observation time if in sequence can be 14.33 hr (51,500 sec).

If enough volume exists behind the large telescope mirror, a multiple range echelle spectrometer may be used with all portions of the desired band integrated and registered simultaneously.

h. Polarimetry. A single-channel polarimeter can be used at the Cassegrain focus of the large telescope. The polarimeter should be mounted and operated in a manner to minimize polarization effects introduced by the telescope optics. A typical envelope for enclosing polarimeter components so that the polarimeter may be mounted on the telescope axis is shown in Figure 2-5.

*With the brighter stars and a smaller integration time, 0.025 Å resolution may be achievable.

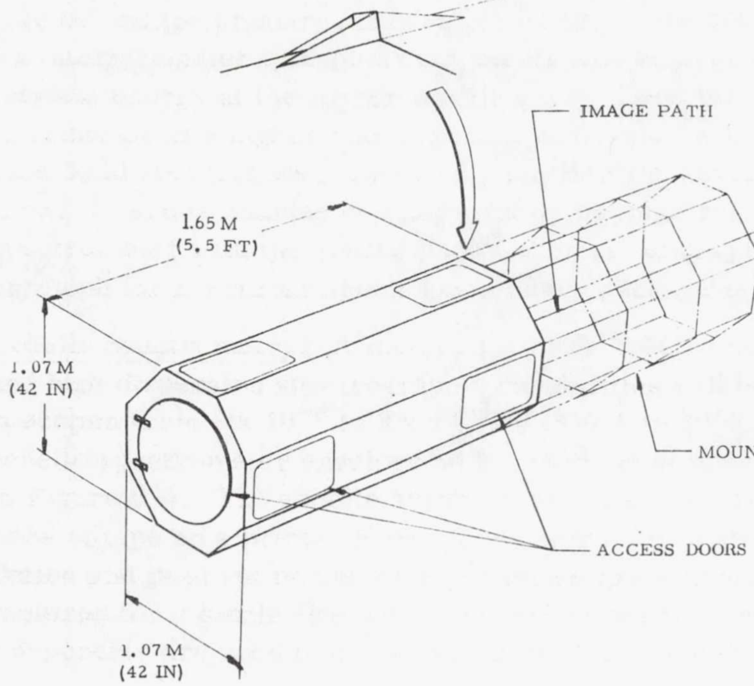


Figure 2-5. Typical Polarimeter Package Envelopes

2.4.2.3 Observation/Measurement Program. The following in-space preparation and experiment operations program is expected for initial setup, experiment operations per stellar object, periodic maintenance, and updating after optical technology experiments are completed on the same or a previous telescope (to develop most effective methods and equipment within allowable cost limits). Steps in the observation measurement cycle may be omitted, according to confidence in previous information, or delayed if continuous observation sequence is not desired or possible.

Exp.	Task	Hours Per Ops Cycle	Number of Expected Cycles
Px	Initial Preparation & Checkout (2 men)	8	1
a.	Focus and Alignment	0.7	Once per Stellar Object
b.	Guide Star Acquisition	0.1	Once per Stellar Object
c.	Observed Stellar Object Acquisition + Location	0.1	Once per Stellar Object

Exp.	Task	Hours Per Ops Cycle	Number of Expected Cycles
d.*	High Resolution Electronic Imaging	Up to 0.7	Once per Stellar Object
e.*	Optional Backup Film Imaging	Up to 4.0	When manned visiting vehicle in vicinity
f.*	Spectrophotometry	Up to 4	Once per Stellar Object
g.*	Spectroscopy (3 Spectrometers*)	0.7 to 4.6	Once per Stellar Object
h.*	Optional Polarimetry	Up to 0.7	Optional per Stellar Object
i.	Typical Full Observation Sequence	14.9	Per Stellar Object
j.	Scheduled Maintenance (2 men)	3.0	Per 180 Days
k.	Unscheduled Maintenance	3	Unexpected

NOTE: Earth observation or telescope carrier vehicle station keeping operations will break up above schedule into time segments. However, observation sequence could be completed in 24 hours per bright-enough source.

*7 experiment instruments

2.4.2.4 Stellar Observation Experiments Interface, Support, and Performance Requirements. For stellar observation experiments, the interface, support, and performance requirements are given in Table 2-5.

Since the experiments are usually accomplished in sequence, observation time varies from 40 minutes to many hours per experiment to allow time for photons from faint stars to produce an image or a spectrum by integration of the stellar light increments versus time. Usually a complete cycle can be accomplished per star within 24 hours (estimated average, 14.6 hours) when allowance is made for earth occultation unless one is observing the stellar object near the perpendicular to the plane of the observing vehicle orbit.

For the baseline electronic imaging approach, data storage in the supporting vehicle is desired up to 1.12×10^8 bits obtainable once each 40 minutes. Readout from the imaging tube storage surface in the experiment is desired within 10 to 100 seconds, giving a data transfer rate to supporting vehicle of 1.12×10^7 bps to 1.12×10^6 bps.

Readout from supporting vehicle to ground probably will be at a lesser rate. For the optional film data system, the logistics requirements are given in Table 2-5. Film imaging requires a longer exposure time than is necessary for electronic imaging. Film estimates are based on the data sets per day (24 hr.). Film weights are based on an average film weight of 1.8×10^{-2} kg (0.04-lb) per 9.29×10^{-2} m^2 (ft^2) of roll film and 0.59 kg (1.3-lb) for 254x254 mm x 23 mm glass plates. If dimensionally stable roll film is developed in the future in the 254 mm (10 in.) glass plate size, a weight saving of about a factor of 20 may be achieved.

2.4.2.5 Potential Role of Man. Man will monitor and control operations of the experiment remotely from the ground or from a nearby space station together with the aid of control routines programmed for a control and output information processing computer to be located somewhere in the information flow channels.

Astronomer/astrophysicist/astronauts will be utilized for operations control. The prime investigators or representatives will participate in remote experiment control and monitoring, including vernier operation of final trimming, alignment, guide star acquisition, and stellar object location, since the very fine vernier sensors will be in the particular instrument package being used.

As can be seen by review of the typical observation measurement program and the experiments, a total sequence of about seven kinds of measurements may be accomplished on a stellar object of great interest. Probably a team of observational astronomer/optical scientists will participate in sequence in obtaining the best possible information by carefully controlling, guiding, and adjusting each particular instrument as the observation cycle proceeds. The observer team will be aided by previously planned and simulation tested computer routines designed under prime investigator supervision for each particular experiment or series of observations.

2.4.2.6 Available Background Data. See Section 2.11.

2.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

Table 2-6 accumulates totals or maximum interface, support and performance requirements according to the way that they combine. Since operation of the large telescope facility is expected to be continuous around the clock, maximizing the information return versus time, the requirements accumulated per observation cycle need to be extended for the continuing series of observation cycles.

Since the average set of measurements or images takes about 240 minutes or so to accumulate, the previous set of images or data may be processed or transmitted to the ground during acquisition of the next set of data. Accordingly, means need to be provided to transfer images or data from an experiment image storage in a small time (1 to 4 seconds) to enable continuance of the experiment on the next source without loss of time.

Table 2-6. Advanced Stellar Astronomy Experiment Interface, Support, and Performance Requirements

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	2.4.2 Stellar Observation Experiments								MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	3 or 2 meter dia. Telescope Alignment and Calibration Equip. Control and Info. Proc (Computer) Special Equipment* 1,2,3,4,5,6,8,9, 10,11,12,13,14, 15,16									3 or 2 meter dia. Telescope Alignment and Calibration Equip. Control and Info. Proc (Computer) Special Equipment* 1 through 16
Launch Mass, kg (Weight, lb)	6000 (13,200)								2987 (6600)	6252 (13800)
Logistics Support										
Consumables, kg/180D (lb/180D)	220 (484)								220 (484)	2200 (4840)
Spares, kg/180D (lb/180D)	13.6 (30)									30+
Crew Support										
Initial Setup, Manhours/180D	15									95
Periodic Serv. & Maint., Manhours/180D	6									12
Operation, Remote Control, Manhours/Observation Cycle	14.9									31.7
Electric Power: †										
Peak Load, Watts	715									855
Average Load, Watts	565									405
Standby Load, Watts	265									405
Environmental Control										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	296 ±10									296 ±10
Temp. Range, Ops., °K	274 ±1									274 ±1
Max. Temp. Difference, °K	2**									2**
Relative Humidity, %	< 40								-40	0
Atmosphere Limit, N/m^2 (psi)	0 to 10^5, 1.33×10^{-4} (0-15, < 10^{-6} torr pref)								Manned	0 to 10^5, 1.33×10^{-4} (0-15, < 10^{-6} torr pref)
Cleanliness Class	10,000									10,000
Gravity Level, Max. g	< 10^{-4} operating									< 10^{-4} operating
Radiation Sensitivity, millirad/hr	< 1									< 1
Contamination Sensitivity	Moderate, keep out of contam. cloud									Moderate; min contam. desired

**Max telescope temp diff, but mirror and secondary optics support ΔT, ≤ 0.2°K; instrument package interiors controlled to ≤ 0.1°K

*See Table 2-1 for equipment identification

†Plus 1200 W for 3 meter telescope and 500 W for 2 meter telescope if RAM subsystem excess heat not utilized

Table 2-6. Advanced Stellar Astronomy Interface, Support, and Performance Requirements (Continued)

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	2.4.2 Stellar Observation Experiments							MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:									
Desired Inclination, deg	28 to 55								28 to 55
Acceptable Inclination, deg	> 0							> 0	> 0
Desired Altitude, km (n.mi.)	670 to 830 (360 to 450)								670 to 830 (360 to 450)
Acceptable Altitude, km (n.mi.)	460 to 670 (250 to 360)							460 to 670 (250 to 360)	
Orientation:									
Observed Object Location	Stellar objects ≥ 90° from center of earth and sun								Internal stimuli, Guide stars > 8 m_v Object stars ≥ 90° from center of earth and sun
Observed Object Brightness, mag.m_v	-2.5 to 29							-2.5 to 25	-2.5 to 29
Observation Field of View	2×10^{-5} to 1.16 x 10^{-3} rad (4 arcsec to 4 arcmin)								2×10^{-5} to 1.16 x 10^{-3} rad (4 arcsec to 4 arcmin)
Pointing Accuracy, rad (arcsec)	Pre: 5×10^{-6} (1) Acc: 5×10^{-5} (10)								Pre: 5×10^{-6} (1) Acc: 5×10^{-6} (10)
Pointing Stability, rad/obs time (arcsec/obs time)	2.4×10^{-8} (0.005)							0.008	2×10^{-8} rad (<0.005)
Slew Rate, max., rad/sec (arcsec/sec)	Desired 1.75×10^{-3} 360							72, 360	360
Slew Rate, min., rad/sec (arcsec/sec)	2.4×10^{-8} (<0.005							2×10^{-8} (< 0.005)	2×10^{-8} (<0.005)
Pointing Hold Time, sec	360 to 86,400							360 to 14,400	360 to 86,400
Data Requirements/Observation Cycle:									
Spectral Range									
Imaging Data									
Desired Resolution, (spatial or spectral)	2×10^{-11} to 5 x 10^{-13} m (0.2 A to 0.005 A) 2×10^{-8} to 2×10^{-7} rad (0.004 to 0.004 arcsec)								Optical surfaces to 1.3×10^{-8} m λ/50; spectra to 5×10^{-13}m (0.005Å) Angle to 2×10^{-8} or 2×10^{-4} rad (0.004 or 0.04 arcsec)
Equiv. Image Format Size, mm	100 x 100							25.4 x 25.4	100 x 100
Picture Elements/Image	1.6×10^{7}							10^{6}	1.6×10^{7}
Images/Data Set	Up to 16							Up to 16	Up to 16
Images/Second	1.15×10^{-5} to 1								1.15×10^{-5} to 1
Photometric Resolution, %, bits	1, 10^{-4}, 7 bits***								1, 10^{-4}, 7 bits**
Equiv. Analog Data, mHz	11								11 if used
Equiv. Digital Data, bits/image	1.12×10^{8}							7×10^{6}	1.12×10^{8}
Non-Imaging Data: Command Data, bps	≤ 10^{3}								10^{3}
Science/Exp. Data, bps	≤ 10^{6}							1.26×10^{5}	10^{6}
Housekeeping Data, bps	2×10^{3}								2×10^{3}
Special Requirements:									
Updating Cycle, Years	1 to 2							0.5 to 2	0.5 to 2
Mass, kg/yr (Weight, lb/yr)	175 min, 306 max (375 min, 675 max)							175 (375)	-306 (675) max
Volume, m^3/yr (ft^3/yr)	0.69 min, 1.3 max (26.3 min 50 max)							(54.4)	2.2 78.1 max

** Logarithm to accommodate orders of magnitude

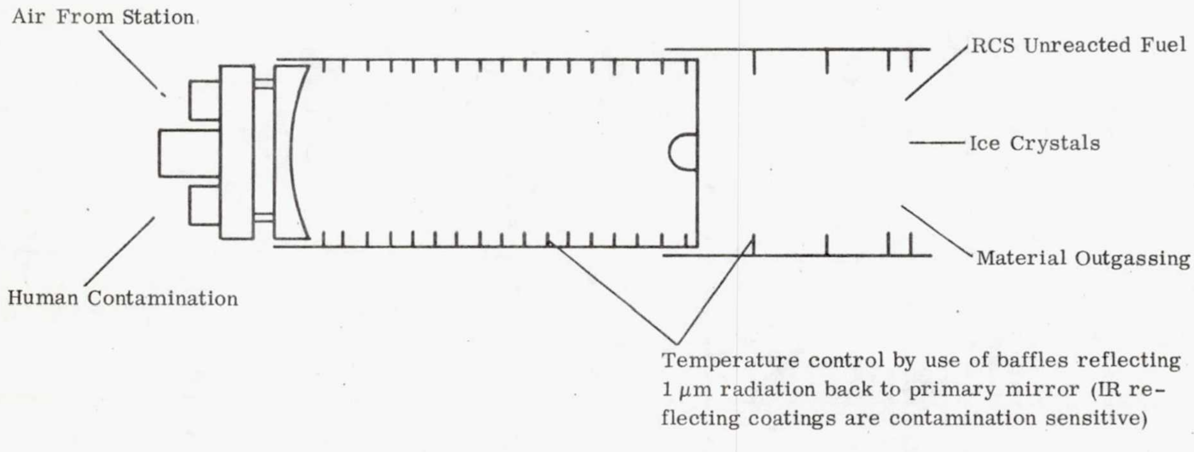
***May be coded for orders of magnitude of brightness (i.e., magnitude or logarithm)

If the same instrument is not used again for obtaining images or data versus time (for time variant astronomical effects), the requirement for short term transfer of the data is relaxed but the supporting vehicle absorption of the data should not take too long since the imaging storage-device integration time period is probably at its maximum (about 40 minutes). Waiting too long may cause contamination of the data from interference or from noise characteristics of the particular image storage tube.

It appears that, due to the normally sequential nature of the operations, if one is willing to accept sometime delay in getting the data back to ground control points, the data problem can be alleviated somewhat. However, the monitoring and control team needs minimum-delay data to enable best (timely) control of the experiments. High-resolution image data then represents a bandwidth problem.

The heat loss from the large telescope will be dependent upon the final telescope design selection. However, preliminary calculations based on a nominal design indicate that a heat loss of 500 watts should be expected for the two-meter telescope, and 1200 watts for the three-meter telescope, assuming a 283° K (50° F) primary. This heat will have to be supplied by the RAM, but will not necessarily be an electrical power requirement if RAM subsystem heat is properly utilized. It should be noted that these values are strictly preliminary and that significant savings might result by finesse in the actual telescope design.

Figure 2-6 summarizes several options that might be considered in obtaining thermal control, angular stability, and contamination protection. However, one must remember that, for stability, many of the experiments demand on-axis operation to minimize field distortion effects.



Requirements	Countermeasures	
Cleanliness Consistent with 10 year Operational Life Time Using Reasonable Countermeasures	Doors Baffling Heaters on Sensitive Instruments Instrument Covers Materials Testing Procedures	Materials Selection Criteria Clean Room Handling Controlled Vent of Station Waste Cleaning & Replacement Internal Instrument Purging

Figure 2-6. Contamination Interfaces (Sources) and Countermeasures

2.6 FPE POTENTIAL MODE OF OPERATION

The advanced stellar astronomy experiments with large optical telescopes present an opportunity to obtain stellar object images and spectral information with a minimum of interference from man's body motions, mechanical vibration, and sky brightness background. It is believed that maximum resolution both in angle and in wavelength can be best obtained in a free-flying optimally balanced unmanned vehicle capable of being periodically serviced and updated by man. Because of the omnidirectional point requirements associated with this stellar mission and because of the potential pointing conflicts which will exist between the module and Space Station, a free-flying operating mode is recommended.

Contamination levels also will be lower if the telescope-carrying vehicle can be operated outside the Space Station wake region and if its optical surfaces are protected when it is docked for servicing or when propulsion is being utilized. Current estimates indicate that the large telescope vehicle should be stationed some tens or hundreds of miles ahead of the Space Station, but at altitudes where it may efficiently (low propellant usage) be brought back to the station for servicing.

The application of this experiment package to each of the proposed mission modes is as follows:

Mission A - Limited On-Orbit Stay Time With Space Shuttle. This mission has limited potential for the Large Stellar Telescope due to the short on-orbit stay time and the need for many hours of observation time to utilize the telescope capability. One attractive possibility is to take advantage of this sortie-type mission to accomplish the basic technology experiments and check out the telescope in orbit. It could then be returned to earth, debugged, and then relaunched for scientific observations in the Mission B or Mission C mode.

Mission B - Extended Orbit Stay Time Revisited By a Shuttle. This mission is very attractive for the Large Stellar Telescope (LST). The RAM/LST could be launched by the Shuttle, deployed, checked out, and left for extended observations. Either film or electronic imaging can be used in this mode; however, the film option will require more frequent logistics missions for support. Revisits by a Shuttle in six-month to one-year intervals would provide for film logistics (if used), maintenance, repair, and sensor updating. It would also allow extra-high-resolution imaging during the short stay time of the Shuttle by using the back up film plate cameras. The plates could then be returned in the Shuttle. After several years in orbit, the entire RAM/LST might be returned to earth for major repair and refurbishment if required.

Mission C - Extended Mission In Conjunction With Space Station. This mission is of course ideal for the LST. The RAM/LST would operate remotely, but astronomer/astronauts would be available for real-time control, and for rapid response for emergency repairs, etc. This would definitely be the preferred mode if film is used

(as the prime method of data taking). One problem added in this Space Station mode is contamination; however, with care, and utilizing remote operation, it can be minimized. Attached operation definitely does not appear practical.

2.7 ROLE OF MAN

Man's role in orbit with respect to the stellar observations will be quite limited, since real-time ground control of target selection and mission programming is important to the objectives of the large telescope facility. However, the Space Station crew will monitor module subsystems during its remote operation, issue the commands necessary to perform station-keeping maneuvers and momentum dump operations, initiate the automatic rendezvous and docking sequence and monitor its execution, prepare the module for entry once it is docked, service and maintain all subsystems, resupply propellants and other expendables, prepare the module for launch, conduct module launch operations, establish initial station-keeping trajectory and, if automatic tracking fails, manually dock the module from a remote control console located on the Space Station.

During the optical technology experiments, optical scientist/astronauts and optical technician astronauts in a vehicle capable of servicing and maintenance will periodically reconfigure the telescope and its experiments as the experimental optimization process proceeds with experiment sequence (see Section 2.4.1).

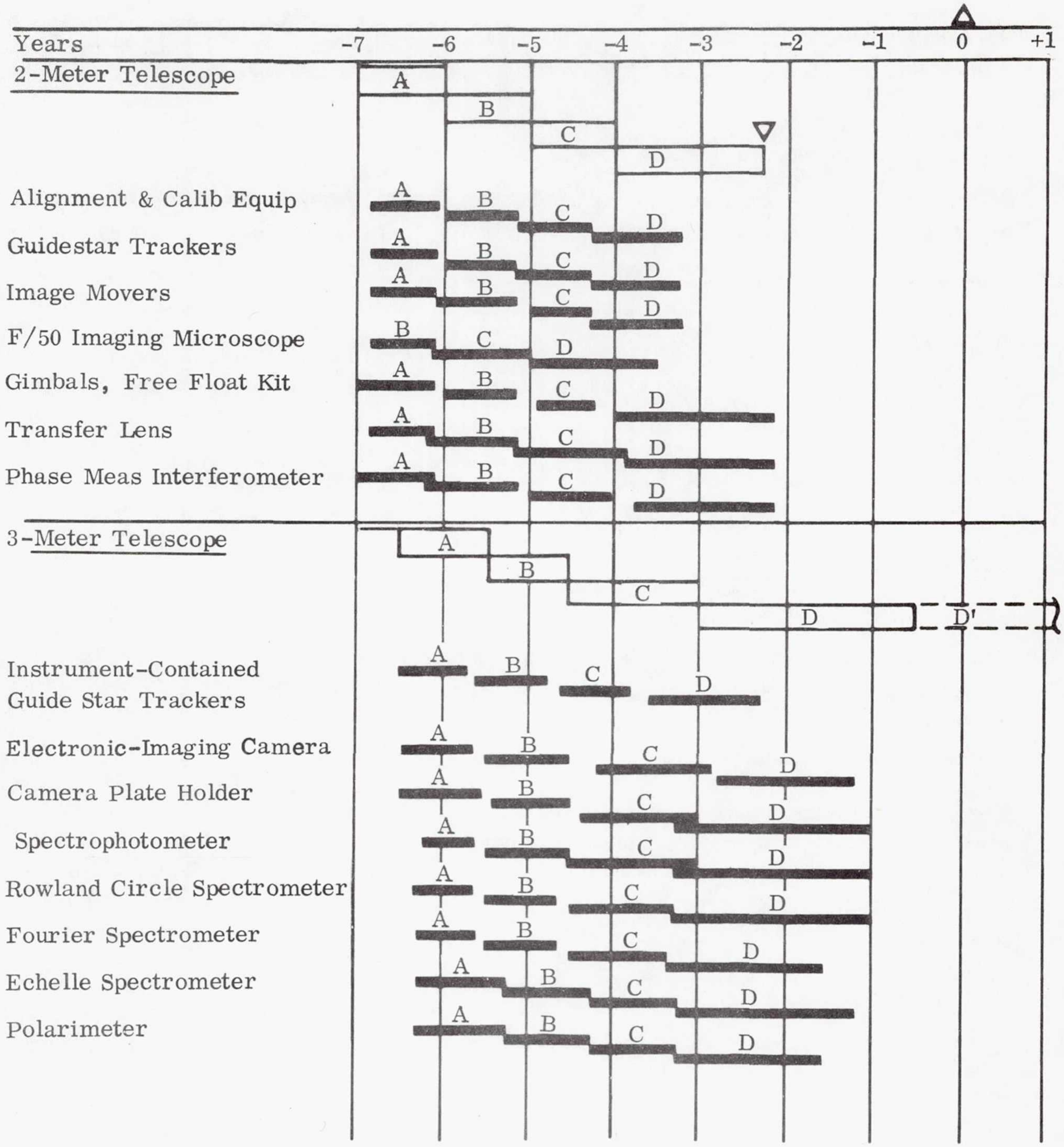
When a routine observation/measurement set of capabilities have been established for a large telescope and its installed experiment instruments, man will service, maintain or update the telescope facility only once per six months. The rest of the time, the facility is operated around the clock with adequate shifts of observers and controllers at a ground station (or a nearby Space Station) proceeding with the experiment measurement program as selected from candidate applications of prime investigators for participation in the effort.

During each of these experiments, probably planned ahead for several months by each investigator, the investigator or his representatives will be on hand to remotely control the parameters of the observation, much as is done nowadays at ground-based observatories. The prime investigator's computer program control sequences will aid man in getting each particular observation accomplished.

2.8 SCHEDULE

Table 2-7 shows estimated schedules based on the state of the art for concept definition, development, and fabrication of each of the two proposed telescopes and the associated experiment equipment.

Table 2-7. Schedules



▽ = Ready for Flight

△ = First Flight Available

A, B, C, D = PHASE

D' = Extension for Utilizing Information from Technology Experiments

2.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Ground support equipment and facilities during the prelaunch period will include the following:

a. Facilities. Optical Support Laboratory with 10,000 class cleanliness, with a room having stellar viewing access.

b. Transportation and Handling. Shipping and Storage Containers (constant temperature control); Lifting Adapters.

c. Test and Checkout. Simulation Equipment, including telescope and experiment monitoring and control positions, equivalent to the ground-based control center facilities.

   Seven special optoelectronic test sets, one for each of the seven observation experiment packages.

   One test set and master calibration kit for built-in telescope alignment and calibration.

2.10 SAFETY ANALYSIS

The incorporation of interlocks and discharge devices is required in the experiment equipment to prevent the astronaut from being exposed to high voltages of electronic imaging devices during the maintenance, servicing and checkout operations. Suitable bonding provisions will be made to ensure that all chassis and frames are at a common potential.

The experiment hardware shall be designed to preclude exposure of the astronaut to any hazard during his performance of maintenance, repair, checkout or operating tasks. Power, liquids and gases shall be removed or secured prior to the performance of replacement or repair operations. Systems reactivation by restoration of power or pressure shall require a deliberate action by the astronaut performing the maintenance. The hardware shall be devoid of sharp corners, rough surfaces or uninsulated wiring.

Pressurization of the entire telescope housing surrounding the secondary mirror and star tracker may not be possible without an enormous weight penalty for the end closure. Maintenance of the secondary mirror servomechanisms or the star trackers would then require EVA with some inherent risks, such as tether entanglement.

2.11 AVAILABLE BACKGROUND DATA

Advanced Astronomy Missions Concept Study, Task 416 - 0.1A, NAS8-24000, Martin Marietta Corporation, Denver, Colorado.

Optical Technology Apollo Extension System, (OTES) Phase A Study, NAS8-20255, Perkin-Elmer, Norwalk, Connecticut.

Orbital Astronomy Support Facility (OASF) Study, NAS8-21023, McDonnell-Douglas Corporation, Huntington Beach, California.

Large Telescope Experiment Program, Vol. 1, NAS8-21497, Perkin-Elmer, Norwalk, Connecticut.

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SECTION 3

ADVANCED SOLAR ASTRONOMY

3.1 GOALS AND OBJECTIVES

The goals and objectives of manned orbital advanced solar astronomy are:

a. Extremely high resolution visible and UV studies of the solar granular structure and areas of high solar activity.

b. Correlated XUV and X-ray observations with higher spatial and spectral resolution using larger apertures, more efficient reflective surfaces, and improved instrumentation.

c. Development of solar astronomy facilities designed to take maximum advantage of man's presence (some of these modules may operate detached from the Space Station).

d. A long-lifetime solar information acquisition system capable of being efficiently and conveniently operated either from a Space Station or the ground. (Such an information acquisition system will possibly involve the use of advanced communication satellites for real-time ground control.)

The dramatic influence which the Sun has on the Earth, its atmosphere and magnetic field, as well as the improved knowledge of stars which will result from solar studies, is justification for intensive solar studies. Detailed image, velocity, and spectral information will be obtainable from 1.1×10^{-6} m (11,000 Å) to 2×10^{-10} m (2 Å) wavelength.

The necessity for man-maintainable systems arises from: the need for versatile telescopes which can be retrofitted with different or improved sensor systems; longer lifetime operation, thus improving the mission success probability; and the astronaut's ability to provide routine servicing as well as to assist in conducting unique observations which require a closer association with the telescope than can be provided by the ground-based observer.

3.2 PHYSICAL DESCRIPTION

The advanced solar astronomical facilities are expected to consist of two groups of instruments: one group which is intended to be used to examine phenomena in solar granular structure and areas of high activity with best-available spectral and spatial resolution, and a second ground which measures phenomena in the region of the solar corona. Instruments listed are representative only and will be further defined in subsequent updating studies. Table 3-1 is a summary of grouped facility and special equipment required to accomplish predicted experiments and observations. Table 3-2 summarizes solar astronomy telescope collector parameters.

Table 3-1. Summary of Solar Astronomy Equipment

		FACILITY ITEMS				KINDS OF SPECIAL EQUIPMENT*													
		A	B	C	D	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	EXPERIMENT CLASS	1.5-M PHOTOHELIOGRAPH	0.25-M XUV SPECTRO-HELIOGRAPH	0.5-M X-RAY TELESCOPE	CORONAGRAPH ASSEMBLY	ALIGNMENT + CALIB EQUIP.	ASPECT (SPOTTING) SENSOR**	ECHELLE SPECTROGRAPH	LYOT BIREFRINGENT FILTER	ELECTRONIC IMAGING CAMERAS	OPTICAL TRANSMISSION FILTERS	MAGNETOGRAPH ANALYZER	BAND SELECTION GRATING	X-RAY IMAGING SENSOR	TRANSMISSION GRATING	PROPORTIONAL COUNTER	CRYSTAL SPECTROMETER		
SELECTED SOLAR AREA CENTERED	PHOTO HELIOGRAPH																		
	FOCUS + ALIGNMENT	•				•	•	•	•	•	•	•							
	OBSERVATION AREA LOCATION	•				•													
	ECHELLE SPECTROSCOPY	•				•	•	•		•									
	HYDROGEN ALPHA	•				•	•		•	•									
	WHITELIGHT IMAGING	•				•	•			•	•								
	UV IMAGING	•				•	•			•									
	SOLAR MAGNETIC MEAS.	•				•	•		•	•		•							
	XUV SPECTROHELIOGRAPH	•	•			•	•			•			•						
	FOCUS + ALIGNMENT	•	•			•	•												
	OBSERVATION AREA LOCATION	•				•	•												
	MULTIPLE XUV IMAGING	•	•				•						•						
	X-RAY TELESCOPE			•		•	•							•	•	•	•		
	IMAGE STABILIZATION	•		•			•							•					
	HI RES IMAGING + LOW RES SPECTROMETRY	•		•			•							•	•				
	SPECTRAL ENERGY DISTR.	•		•			•									•			
	HI-RES SPECTROMETRY	•		•			•										•		
SOLAR DISK CENTERED	CORONAGRAPH				•	•	•												
	INNER CORONA IMAGING				•		•		•	•									
	OUTER CORONA IMAGING				•		•		•	•									

*To be extended later to exact equipment.

** = Optional cross-correlation and pointing aid from other facility items.

Table 3-2. Summary of Solar Telescope Parameters

PARAMETER	SELECTED SOLAR AREA CENTERED INSTRUMENT GROUP			SOLAR DISK CENTERED INSTRUMENT GROUP	
	1.5m PHOTO HELIOGRAPH	XUV SPECTROHELIOGRAPH	X-RAY TELESCOPE	1 TO 6 SOLAR RADII CORONAGRAPH	5 TO 30 SOLAR RADII CORONAGRAPH
Aperture, meters	1.5	0.25	0.5	0.0245	0.04
Primary focal length, meters	5.35	3	-	0.315	0.09
Effective focal length, meters	75	3	5	0.315	0.09
Total field of view, radian (arcmin)	3.2×10^{-4} 1.1	9.3×10^{-3} 32	2.9×10^{-3} 10	5.7×10^{-2} 195 (3.25°)	0.26 900 (15°)
Angular resolution (design goal)					
On axis, radian (arcsec)	2.4×10^{-7} at 6.2×10^{-7} m (0.05) at (6200 Å)	5×10^{-6} at 1.7×10^{-8} m (1) at (170 Å)	2.4×10^{-5} at 6×10^{-10} m (5) at (6 Å)	5×10^{-5} at 5×10^{-7} m (10) at (5000 Å)	1.6×10^{-5} at 5×10^{-7} m (30) at (5000 Å)
Poorest in field of view, radian (arcsec)	5×10^{-7} at 6.2×10^{-7} m (0.1) at (6200 Å)	5×10^{-6} at 1.7×10^{-8} m (1) at (170 Å)	9.7×10^{-6} at 6×10^{-10} m (20) at (6 Å)	2.1×10^{-5} at 5×10^{-7} m (45) at (5000 Å)	2.9×10^{-5} at 5×10^{-7} m (60) at (5000 Å)
Obscuration of aperture, %	5	0	93.5	3.4 (occulted area in focal plane)	6.5 (occulted area in focal plane)
Minimum wavelength, meters (Å)	1.3×10^{-7} (<1,300)	1.7×10^{-8} (170)	2×10^{-10} (2)	4×10^{-7} (4,000)	4×10^{-7} (4,000)
Maximum wavelength, meters (Å)	1.2×10^{-6} (> 12,000)	6.5×10^{-8} (650)	10^{-8} (100)	10^{-6} (10,000)	10^{-6} (10,000)
Primary f/No.	6	12	-	12.9	12.9
System f/No.	50	12, 24	10	12.9	12.9
Scale at system focal plane, radian/mm (arcsec/mm)	1.36×10^{-5} (2.75)	3.4×10^{-4} (69)	2×10^{-4} (41.2)	3.4×10^{-3} (690)	1.31×10^{-2} (2700)
Resolution at system focal plane, lines/mm	27.5	69	10	69	90
Linear field of view at system focal plane, mm	24	27.9	14.6	17.9	24
Auxiliary optics to adjust image size for effective instrument use	Yes (up to 100×100 mm)	Yes (up to 100×100 mm)	No	adj to 100×100 mm	adj to 100×100 m
Telescope + Instr Housing Assembly:					
Size, m (ft)	12.3×2.5×1.8 (40.44×8.15×5.82)	3.43×1.3×0.92 (11.25×4.5×3)	7.1×0.94 D (23.5×3.08 D)	3.66×1.4×0.99 (12×4.68×3.26)	
Volume, m^2 (ft^3)	54.2 (1918)	4.25 (150)	6.2 (219)	6.1 (216)	
Weight, kg (lb)	1582 (3490)	408 (900)	402 (885)	405 (895)	
Associated Exp/Instr Weight, kg (lb)	500 (1100)	23 (50)	23 (50)	27 (60)	
Gross Weight Per Assembly, kg (lb)	2082 (4590)	432 (950)	424 (935)	433 (955)	

3.2.1 BORESIGHTED SOLAR INSTRUMENT GROUP. The high-resolution boresighted solar instrument group capable of being pointed at any selected location on the sun will consist of:

a. 1.5-meter diffraction-limited photoheliograph.

b. 0.25-meter XUV spectroheliograph.

c. 0.5-meter X-ray telescope.

This group of instruments will be mounted together on the same supporting vehicle or platform. Instrument axis will be aligned such that boresighting error at the solar location examined will not exceed 5×10^{-6} rad (1 arcsec). Mounting rigidity between instruments in the assembly shall be sufficient to limit angular jitter between instruments to less than 5×10^{-7} rad (0.1 arcsec). Figure 3-1, Boresighted Solar Astronomy Instrument Group, shows a typical arrangement and layout of the correlated instruments.

3.2.1.1 Telescope for Photoheliograph

a. General Assembly Characteristics. The solar telescope for the 1.3×10^{-7} m (1300 Å) and longer wavelength range is a Gregorian telescope of 1.5-m aperture and 75-m focal length. The collecting optics consist of a primary mirror of 1.5-m aperture and about 5.35-m focal length, and a secondary mirror providing about 14.0 diameters of magnification. The image is brought to a focus about 0.3-m behind the primary mirror (see Figure 3-2). Optics shall not inhibit use of the telescope for high resolution solar magnetic and velocity measurements. A heat dump mirror reflects 90% of the thermal energy backout into space.

   The instrumentation section behind the primary mirror will accommodate a triple-range echelle spectrograph assembly, a UV camera, a white light camera, a Hydrogen-Alpha camera, and two solar magnetographs.

   The solar telescope guidance supplied by the supporting vehicle will mainly be inertial, with updating coming automatically from reference guide star trackers (offset), the image of the sun's limb, or manually trimmed by an observer viewing an image of the sun on a monitor, and guiding to keep a specific feature of interest in the field of view or on the slit of a spectrograph.

   The basic characteristics of the 1.5-m UV-visible normal-incidence solar telescope are tabulated in Tables 3-2 and 3-3.

b. Telescope Focus and Alignment Control. The secondary mirror assembly will be equipped with three drive mechanisms which, when operated separately, will change the tilt, and when operated simultaneously, will change the primary-to-secondary separation.

   Alignment is verified using an integral alignment sensor device located in the focal plane, light sources within the alignment sensor, and the secondary mirror.

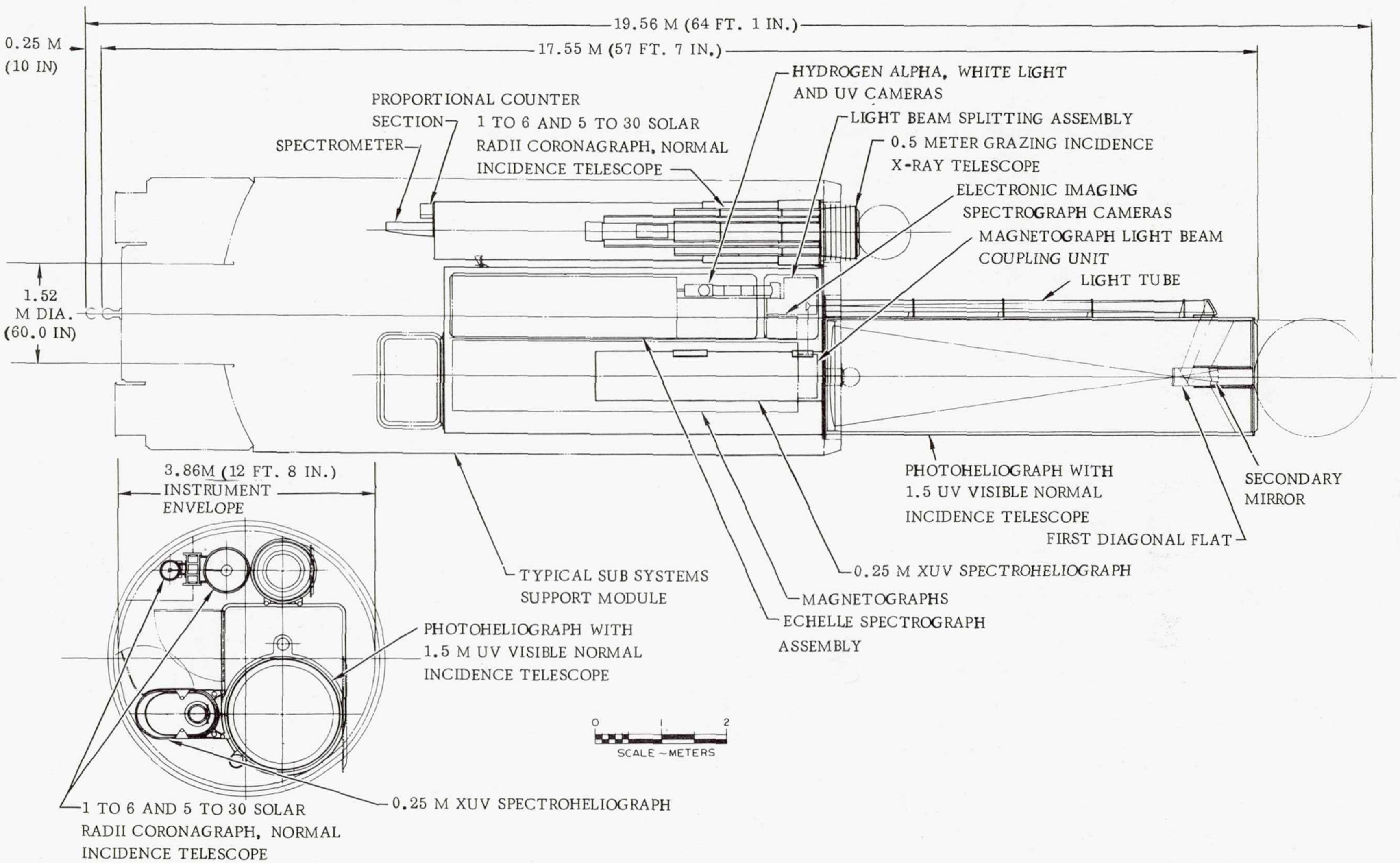


Figure 3-1. Typical Advanced Solar Astronomy Facilities Grouping

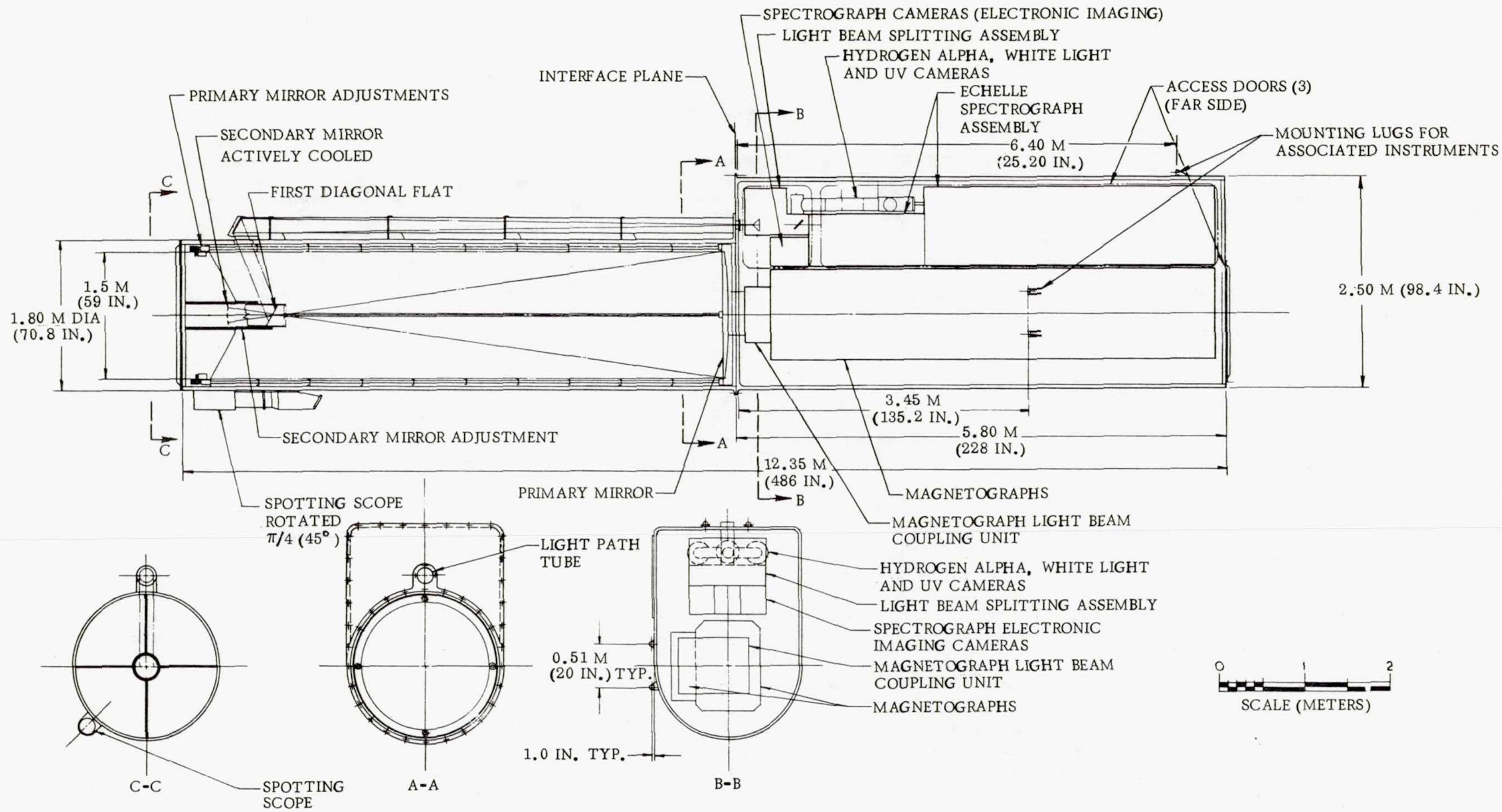


Figure 3-2. Solar Astronomy Photoheliograph with 1.5 Meter Diffraction Limited UV Visible Normal Incidence Telescope

Table 3-3. 1.5-Meter Solar Photoheliograph Mass (Weight) Summary

	Mass, kg	Weight, lb
Telescope Tube	725	1,600
Secondary Mirror	45.4	100
Secondary Mount	18.2	40
Primary Mirror	326	720
Primary Mount	113.5	250
Isolators	40.8	90
Rings	36.2	80
Support Base	90.8	200
Experiments	500	1,100
Exp. Structure Support	158.8	350
Support Instrumentation	90.8	200
Total	2,082	4,590

3.2.1.2 XUV Spectroheliograph. The 0.25-m XUV spectroheliograph is a special-purpose instrument designed to record the image of the solar disk or a selected spot at several extreme UV wavelengths simultaneously (Figure 3-3). The telescope has a concave grating with figure corrections to improve the image quality. The grating is plated with gold and ruled at 3,333 lines/mm. An aperture of about 0.25-m with a focal length of 3-m provides the scale factor and image brightness required.

An unbacked thin film of aluminum passes the desired wavelength transmission range, while reflecting the much more intense visible energy. As a further protection, thermal mirrors are placed at strategic points to reflect the zero-order image and the first-order visible range energy back out into space through the entrance aperture.

An image intensifier followed by an electronic camera tube will register the selected XUV images for sequential transfer to data processing or transmission to experiment data delivery points on earth.

The XUV spectroheliograph will be grouped with the 1.5-m photoheliograph and the solar X-ray telescope to enable imaging and spectrometry to be accomplished simultaneously on radiation received from any selected spot or area on the sun. A shutter operable on command will enable control of exposure time.

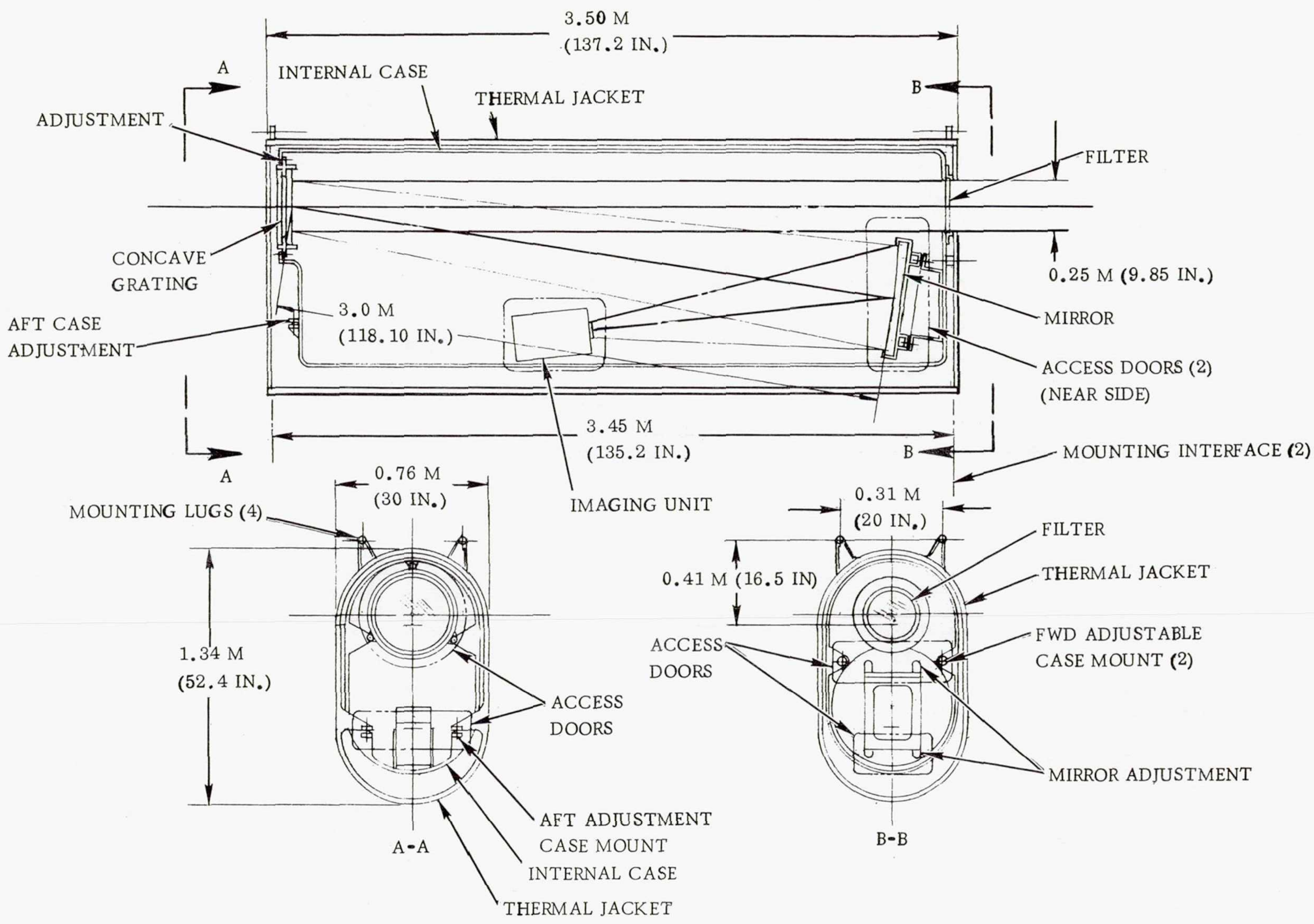


Figure 3-3. 0.25 Meter XUV Spectroheliograph, Normal-Incidence Telescope, Solar (Typical)

The supporting vehicle will provide pointing and angular stability for the grouped instruments including the XUV spectroheliograph so that images and spectra versus wavelength band may be readily correlated. Table 3-2 shows collector parameters of the XUV solar telescope.

3.2.1.3 0.5-Meter X-Ray Telescope. The X-ray telescope is a large grazing-incidence instrument of the "inside-inside" Wolther Type I category, in which both elements are concave. It has an aperture that is nominally 0.5 m and an image plane about 5 m from the objective. The telescope has an overall length of 7.2 m. Table 3-2 shows X-ray telescope collector parameters. Figure 3-4 shows a typical X-ray telescope configuration.

The X-ray telescope needs signals from an optical telescope which enables guiding the solar telescope array and jitter correction and, in addition, provides a means of stabilizing the imaging and/or the instrument package at the focus of the X-ray telescope. The X-ray instrumentation is installed on a turntable turret, or linear positioning device, that can introduce any of the instrumentation devices, one at a time, to the telescope focus. Three instrumentation devices are included: a proportional-counter detector, a spectrometer, and an imaging system. Space remains for the installation of additional instrumentation.

Because of the extremely short wavelengths dealt with in this region, 2×10^{-10} to 4×10^{-9} m (2 to 40 Å), the surface smoothness must be held to extremely small RMS variations, on the order of 10^{-10} to 2×10^{-10} m (1 to 2 Å). Pitting, due to the impingement of high-energy particles, that could be tolerated where longer wavelength radiation (for example, XUV or longer) is involved, would degrade the effectiveness of the grazing-incidence reflective surfaces and shorten their useful lifetime. Electrostatic shields are suggested, therefore, as a possible means of reducing the number of high-energy-particle impingements on the grazing-incidence reflective surfaces. This reduction would be accomplished by deflecting charged high-energy particles by the imposition of an electrostatic field.

3.2.2 SOLAR-DISK-CENTERED ASTRONOMY INSTRUMENT GROUP FOR CORONA MEASUREMENTS. The instrument group for measurement of corona phenomena will consist of:

a. 1 to 6 Solar Radii Coronagraph.

b. 5 to 30 Solar Radii Coronagraph.

The solar-disk-centered instruments are mounted together in a rigid assembly which is kept pointed at the center of the solar disk by vehicle motions or platform gimballing. If the boresighted and disk-centered instrument groups are mounted together in the same vehicle, the disk-centered instrument assembly should be gimballed. Figure 3-5 shows a typical arrangement of the solar-disk-centered instruments in one rigid assembly.

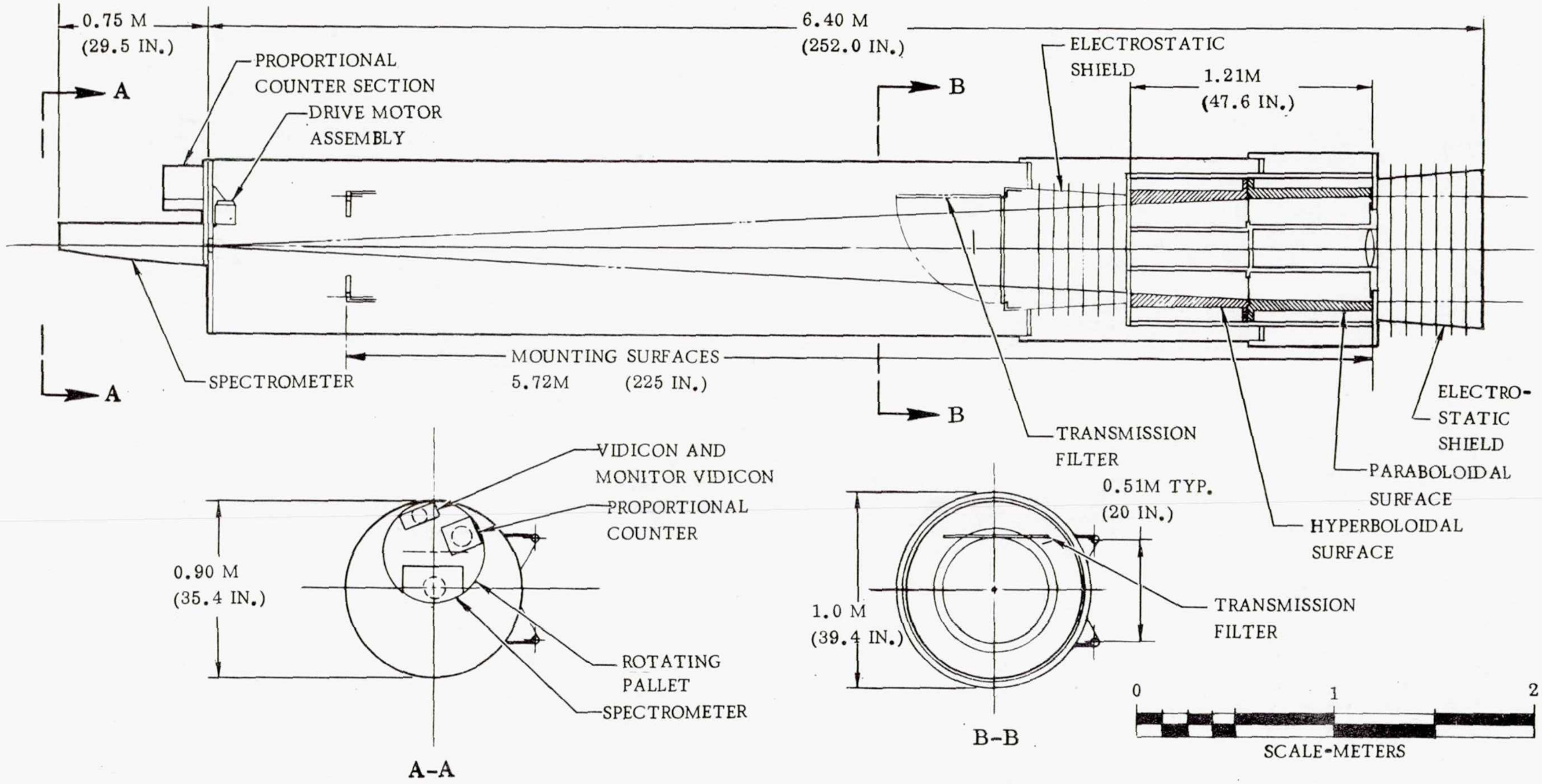


Figure 3-4. 0.5 Meter Grazing Incidence X-Ray Telescope

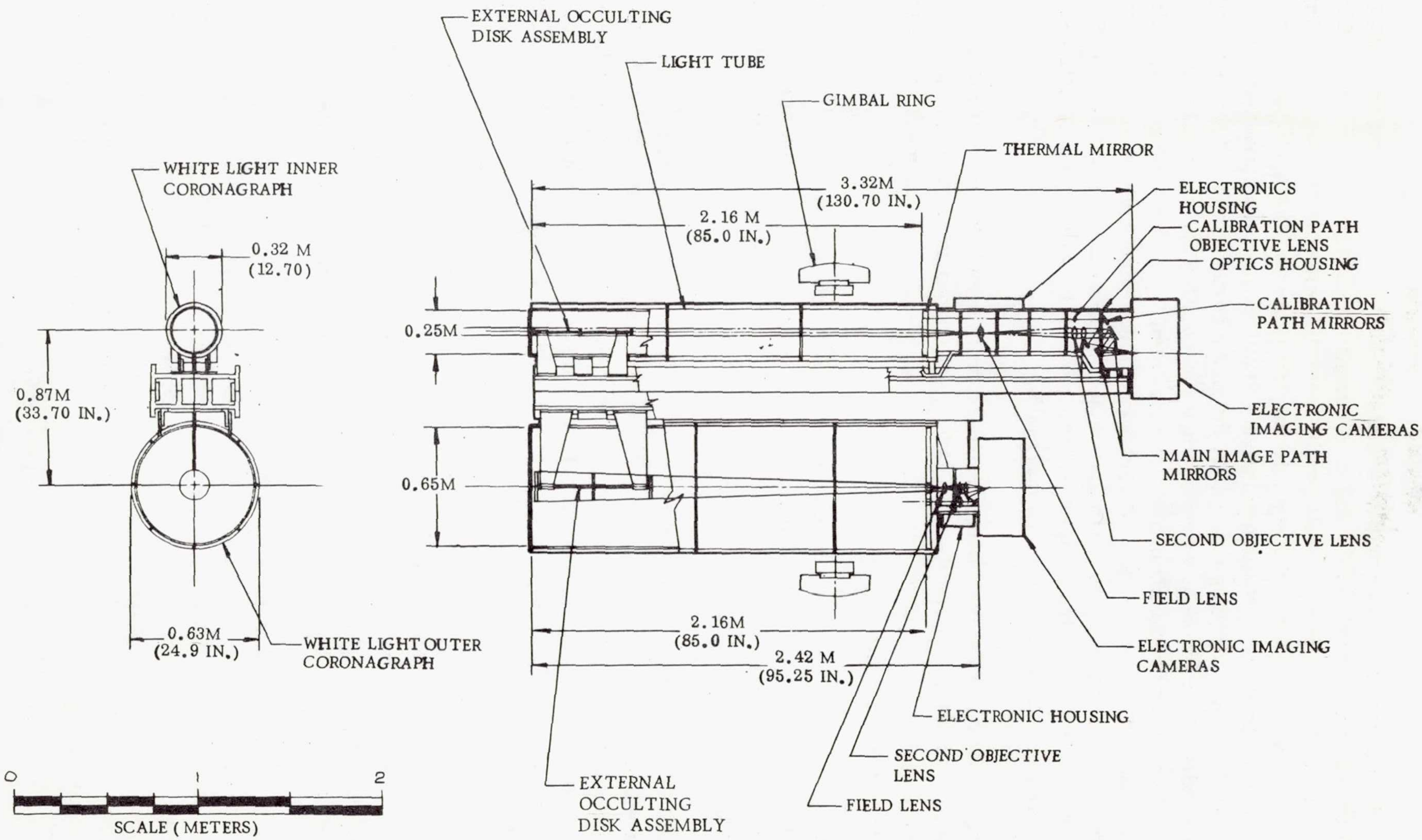


Figure 3-5. 1 to 6 and 5 to 30 Solar Radii Coronagraph, Normal Incidence Telescope

The 1- to 6-solar-radii coronagraph combines with the 5- to 30-solar-radii coronagraph to observe white-light emission of outward-moving plasma clouds from the solar limb to a distance of 30 solar radii from the center of the sun. Coverage of this considerable region is divided into two instruments for the following reasons: (1) the two instruments are each relatively small in size as contrasted with one instrument of unwieldy proportions; (2) the inner coronagraph, which requires a much smaller field of view, provides higher resolution for a given image size in the region where the coronal phenomena are expected to be much more interesting; (3) the range-of-response requirement for the recording devices is considerably relaxed by splitting into two parts the six-to-eight-order-of-magnitude difference in radiation flux levels between the solar limb and 30 solar radii. Table 3-2 presents collector parameters for both coronagraphs.

The combination of the two coronagraphs permits simultaneous recording of both inner and outer coronas. It permits each part of the corona to be recorded at an appropriate scale factor, thus taking advantage of a larger effective format to show the inner corona in more detail.

If the coronagraph assembly is assigned to a supporting vehicle or platform that directs other instruments toward a particular spot on the sun, the coronagraph assembly will be mounted on limited gimbals, or flexure mounts, that allow the assembly optical axes to be solar-disk centered.

3.2.2.1 <u>1- to 6-Solar-Radii Coronagraph</u>. The 1- to 6-solar radii coronagraph (Figure 3-5) utilizes an electronic imaging tube camera at the focus of a telescope (equivalent to a telephoto lens) to restrict the field of view to 0.052 rad (3 deg) on a 35-mm format. It is fitted out with internal and external occulting disks to block out the direct rays of the sun so that the picture obtained contains the image of the inner corona without the glare of the direct sun. It is composed of four parts: an optical bench, which ties everything together; an optics housing, which provides a support for the objective lens, field lens, relay lens, folding mirrors, elements of the calibration chain, and thermal mirrors; a light tube which serves as a baffle, a support for the instrument cover, and protection for the external occulting disks; and an electronic imaging tube which records the corona images and transfers them to the supporting-vehicle data storage or to data transmission links.

3.2.2.2 <u>5- to 30-Solar-Radii Coronagraph</u>. The 5- to 30-solar-radii coronagraph, shown in outline form in Figure 3-5, consists of a modification of the inner coronagraph design for observation of the outer corona. If the diameter of the light tube is increased from 0.25 m to 0.65 m, the objective lens will have an unobscured view out to a full field of 0.28 rad (16 deg) or a view of the corona from 5 to 30 solar radii. An external occulting disk was sized to provide full occultation of the inner corona to 3 solar radii and no vignetting beyond 5 radii. The length of the light tube was

retained at 2.16 m and the effective focal length of the optics was set at 90 mm to provide for a plate scale including 0.52 rad (30 deg) in a 24-mm format. The image registration device consists of an electronic imaging tube which is capable of transferring the observed image to local data storage or a transmission link.

The optics include an objective lens, a field lens with an occulting disk, and a relay lens pair. The external occulter, 160 mm in diameter, is placed about 2.16 m in front of the objective lens, with the additional occulting disks placed at strategic points in between.

3.3 EXPERIMENT REQUIREMENTS SUMMARY

Table 3-4 shows the summarized Advanced Solar Astronomy requirements in terms of approximate totals for each major assembly grouping. An additional 50% in weight, volume, and power-handling capability in the supporting vehicle is recommended to handle growth, cold plates, baffles, thermal shield, insulation, and access requirements for each assembly. Access is desired all around each major telescope for at least one man. The first three telescope and associated instrument assemblies will be rigidly tied together and to the free-flying supporting vehicle to hold alignment of the telescopes under environmental conditions to less than 4.85×10^{-6} rad (1 arcsec). The coronagraph assembly is separately gimballed to enable solar-disk centering while the other telescopes are pointed toward a specific solar area.

3.4 EXPERIMENTAL PROGRAM

3.4.1 PHOTOHELIOGRAPH EXPERIMENTS

3.4.1.1 Significant Technical Objectives. Correlated profiles of the fine solar granulation structure with extreme spectral and angular resolution – about 2×10^{-13} m (0.002 Å) and 5×10^{-7} rad (0.1 arcsec) respectively - within the spectral band from 1.3×10^{-7} to 1.1×10^{-6} m (1,300 Å to 11,000 Å) are the basic objective. Other objectives are:

a. Development of photoheliograph imaging, spectroscopy, magnetic field measurement, and data handling techniques to enable more continual observation of time-variant solar phenomena.

b. Information on:

   1. Energy transport and conversion.

   2. Solar magnetic fields.

   3. Nonuniform motion of solar surface.

   4. Solar cycle and solar activity quasi-periodic variations.

   5. Physical differences of spicules and embedding media.

Table 3-4. Advanced Solar Astronomy Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg / (lb)	VOLUME m^3 / (ft^3)	ENVELOPE m / (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
3.4.1 1.5 meter photo heliograph measurements	2,082 (4,590)	54.2 (1,918)	12.3 x 2.5 x 1.8 (40.44 x 8.15 x 5.82)	Average: 215 Peak: 245 Standby: 175	Astronomer/ Astrophysicist	Temp. limits: 291 to 297° K Ops atmosphere 1.33×10^{-4} N/m^2 10^{-6} torr Gravity level: 10^{-4} g to avoid flexure Rad sensitivity: 10^{-1} millirad/hr	Set up: 30 min. prior to orbit light side * Ops Cycle: 0.833 min. repeated continually on orbit light side	Picture elements: 1.05×10^8/image set 90 images/set Analog data 4.2 MHz Digital data: 0.4 to 4×10^9 per image set Non imaging data: Science/exp: 2,100 bps Housekeeping data: 5,300 bps	Selectable solar disk obs. area Pointing accuracy: Desired- 5×10^7 rad (0.1 arcsec) Acceptable- 1.2×10^{-5} rad (2.5 arcsec) Pointing stability: 5×10^{-8} rad (0.01 arcsec) per obs period Max. slew rate: 5×10^{-5} rad/sec (10 arcsec/sec) Min. slew rate: 5×10^{-7} rad/sec (0.1 arcsec/sec) Pointing hold time up to 2,200 sec	Desired incl: Sun synchronous Acceptable incl: 55^0 to 0^0 Acceptable alt: 370 to 740 km (>200 to 400 n. mi.)	Simultaneous time correlated measurements of moving solar phenomena Data can be taken in bursts to enable data handling Objective: Max. continual simultaneous data
3.4.2 0.25 meter XUV spectro-heliograph measurements	430 (950)	4.3 (150)	3.4 x1.3 x0.92 (11.25 x 4.5 x 3)	Average: 55 Peak: 70 Standby: 70	Astronomer / Astrophysicist	Ops temp. limits: 290 to 294°K Gravity level to avoid flexure: 10^{-4} g Rad sensitivity: yes	Set up: 30 min. prior to orbit light side* Ops cycle 2.833 min. repeated continually on orbit light side	Picture elements per image set: 2.824×10^7 Analog 2.9 MHz Image sets per sec.: 0.1 to 1 Image digital data: 1.75×10^8 bits/ image Non Imaging data: Science/exp: Housekeeping data: 45	Pointing accuracy: 1.2×10^{-5} rad (2.5 arcsec) Pointing stability: 5×10^{-7} rad (0.1 arcsec) Max. slew rate: 5×10^{-5} rad/sec (10 arcsec/sec) Min. slew rate: 5×10^{-7} rad/sec (0.1 arcsec/sec) Pointing hold time: up to 2,700 sec.	Desired incl: Sun synchronous Acceptable incl: (> 55° to 0°) Acceptable alt: 370 to 740 km (≥200 to 400 n.mi.)	Simultaneous, time correlated data sets Objective max. continual simultaneous data Data can be taken in bursts at intervals to enable handling or processing.

*Observation area location is same for first 3 instruments if sharing precise pointing guidance.

Table 3-4. Advanced Solar Astronomy Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
3.4.3 0.5 Meter dia. X-ray telescope measurements	425 (935)	6.2 (219)	7.1 x 0.94 (23.5 x 3.08 dia.)	Average: 450 Peak: 595 Standby: 260	Astronomer/ Astrophysicist	Ops. temp limits: 290 to 294°K Gravity level to avoid flexure: 10^{-4} g Radiation sensitivity: 1 millirad/hr	Set up: 30 min. prior to orbit light side * Ops Cycle 3.5 min. per new solar location	Picture elements per image set: 2.756×10^5 Image sets per sec: 0.1 to 10 Image digital data to storage: 1.93×10^6 bps Non imaging data: Science/exp: 10,000 bps Housekeeping data: 70 bps	Pointing accuracy: 5×10^{-6} (1 arcsec) Pointing stability: (0.5 arcsec) Max. slew rate: 5×10^{-5} rad/sec (10 arcsec/sec) Min. slew rate: 2.4×10^{-6} rad/sec (0.5 arcsec) Pointing hold time: 360 to 2,700 sec	Desired incl: Sun synchronous Acceptable incl: (≥ 55° to 0°) Acceptable altitude: 320 to 740 km (>200 to 400 n. mi.)	Data correlated with photoheliograph and XUV spectro-heliograph information vs. time Present concept does not allow desired simultaneity of X-ray measurements
3.4.4 Solar coronograph measurements	452 (995)	6.1 (216)	3.66 x 1.4 x 0.99 (12 x 4.68 x 3.26)	Average: orbit light side, 60 W Peak: 60 W Standby: 35	Astronomer/ Astrophysicist	Ops temp. limits: 291 to 297°K Gravity level to avoid flexure: 10^{-4} g Radiation sensitivity:	Set up: 30 min. prior to orbit light side ops Ops cycle: 3 min. repeated continually on orbit light side	Imaging data: Picture elements per image set: 4.609×10^6 Image sets per sec: 5.5×10^{-3} to 1 Image digital data to storage or xmit: 1.2×10^7 Non imaging data: Science: 200 Housekeeping: 20	Pointing accuracy: 3.2×10^{-5} rad (15 arcsec) Pointing stability: 5×10^{-6} rad/sec (1 arcsec/image time) Max. slew rate: 5×10^{-5} rad/sec (10 arcsec/sec) Min. slew rate: 5×10^{-6} rad/sec (1 arcsec/sec) Pointing hold time:	Desired incl: Sun synchronous Acceptable incl: (55° to 0°) Acceptable alt: 370 to 740 km (>200 to 400 n. mi.)	Data correlatable with other solar experiments Solar disk centered May be gimballed to enable solar disk centering when mounted with particular spot pointed equipment

* Observation area location is same for first 3 instruments if sharing precise pointing guidance.

6. Abundances of elements in sun.

7. Clues to solar evolution.

3.4.1.2 Experiment Description

3.4.1.2.1 Photoheliograph Focus and Alignment Experiment. After the photoheliograph initial setup, scientist/astronauts backed up by a ground-based advisory group will carry out a systematic series of procedures and tests to optimize and evaluate telescope and instrument focus and alignment. Time for the photoheliograph assembly to drift out of tolerance will also be determined.

Focus can be adjusted both by moving the camera assemblies and by changing the primary-to-secondary spacing. The television imagery on the monitors enables checkout of the state of focus obtained by automatic devices. The fine adjustment in focus will be made by motion of the entire camera mount parallel to the telescope optical axis, with the aid of a photoelectric focus sensing device independent of electronic imaging tube units.

A further check on alignment will be made by observing the position of a small source of light that will originate at the plane of imaging devices and be returned by small mirrors on the outer end of the telescope. A small solid-state matrix detector as well as a TV camera will be used, and alignment adjusted to position the returned spot.

Other alignment tasks include checking and adjustment of the axis of the mirror, and ensuring that the offset star-reference trackers supplied by the supporting vehicle are correctly related to the telescope axis. Image test sequences may be made to check the correctness of the monitor view of the position of the spectrograph slit through the imaging tube on the boresighted wide-field guide telescope. Corrections are then made if necessary.

3.4.1.2.2 Photoheliograph Observation Area Location. After alignment techniques have been established and a value for time to drift out of tolerance has been determined, techniques for location of specific areas on the sun will be tested and evaluated using the combined guidance capabilities of the supporting vehicle and the photoheliograph assembly. The desired location will be entered into the experiment control keyboard and the boresighted instrument group will be slewed from an initial preparation reference pointing angle to the specific area desired. Monitoring astronomers will be able to observe images of the path scanned and will be able to adjust the pointing angle to concentrate on the specific area of interest. Information obtained in this experiment includes: maximum slew rate enabling instruments to stay within tolerance, adequacy of monitor imaging devices to aid in locating points of interest, accuracy of location of area on sun, and procedures for supporting continuing observation.

3.4.1.2.3 Echelle Spectrograph Measurements. Scientist/astronauts or astronomers, remotely controlling the photoheliograph and a spectrograph assembly, will obtain spectral information to 2×10^{-13} m (0.002 Å) over the range from 1.1 μm to 0.13 μm (11,000 Å to 1,300 Å) as nearly simultaneously as feasible. Sampling of the spectrum will occur at intervals synchronized with other photoheliograph instruments to enable correlated measurements versus time.

The echelle spectrograph assembly mounted on the 1.5-m solar telescope consists of three instruments designed to cover the spectral range from 0.13 μm to 1.1 μm (1,300 Å to 11,000 Å) with no range covering more than an octave. Each spectrograph has its own complete set of optics, including predisperser, echelle grating, focusing mirror and camera (see Table 3-5). Thus, the mirror, grating rulings, film, or image-tube characteristics and coatings can all be selected for the particular wavelength range. The main light beam after passing through a slit in a diagonal optical flat is converted into three light beams by two sets of optical split devices.

The three predisperser gratings are mounted on a platen that can be translated to the three indexed positions to bring the appropriate predispersers into the three beams of light routed from the spectrograph slit. The predisperser collimates the light from the slit into the proper echelle grating, and restricts the wavelength range remaining within the field of the following optics to a single order. Rotation of the predisperser permits the selection of the order to be recorded.

The echelle gratings are also mounted so that they can be rotated about an axis that is perpendicular to both the rotation axis of the predispersers and the axis of the telescope. This rotation determines the portion of the order already selected by the predisperser that will be recorded. Typically, the spectra recorded are between the 40th and 80th orders.

The focusing mirrors collect the light for the spectral range to be recorded and form an image at the image plane. To achieve the desired reciprocal linear dispersion of 10^{-11} m (0.1 Å)/mm, these mirrors must have a focal length of 5 m, thus explaining the large size of the spectrograph.

Three electronic image tube cameras record the spectra from the three spectrographs which have recording formats as indicated in Table 3-5. An alternate to the spectrograph image tubes is use of film cameras.

3.4.1.2.4 Hydrogen-Alpha Measurements. The hydrogen-alpha camera is a narrow-band system for the deep red at 0.6563 μm (6563 Å). The optical path includes a single Lyot-type birefringent filter with a pass-band of 0.5×10^{-10} m (0.5 Å). Since the center frequency of the passband is temperature-sensitive, two heaters will be provided to tune the filter to the proper frequency over a $\pm 2 \times 10^{-10}$ m (2 Å) range.

Table 3-5. Echelle Spectrograph Characteristics

For 1.5-Meter Diffraction-Limited UV-Visible Normal-Incidence Solar Telescope	RANGE 1 CHARACTERISTICS	RANGE 2 CHARACTERISTICS	RANGE 3 CHARACTERISTICS
Wavelength			
Short	0.13 μm (1300 Å)	0.3 μm (3000 Å)	0.6 μm (6000 Å)
Long	0.3 μm (3000 Å)	0.7 μm (7000 Å)	1.1 μm (11,000 Å)
Resolution	2×10^{-13} m (0.002 Å at 3000 Å)	2×10^{-13} m (0.002 Å at 5000 Å)	2×10^{-13} m (0.002 Å at 8000 Å)
Entrance Aperture			
Slit width	20μm	20μm	20 μm
Slit height	2.18 cm 2.9×10^{-4} rad (1 arcmin field of view)	2.18 cm	2.18 cm
Incident Radiation			
f/No. limitation	f/50	f/50	f/50
Spatial resolution	2.75×10^{-9} rad (0.055 arcsec)	5×10^{-7} rad at 0.6 μm (0.1 arcsec at 6000 Å) (diffraction limit)	5×10^{-7} rad at 0.6 μm (0.1 arcsec at 6000 A) (diffraction limit)
Spectral Calibration:			
Predisperser Grating			
Type	Concave	Concave	Concave
Size	41.8 ×20 mm	41.8 ×20 mm	41.8 ×20 mm
Ruling frequency	2230 line/mm	2035.6 line/mm	1257.9 line/mm
Dispersion	10^{-10} m (1 Å)/mm at 0.3 μm (3000 Å)	1.96×10^{-10} (1.955 Å)/mm at 0.5μm (5000 Å)	3.18×10^{-10} m (3.18 Å)/mm at 0.8μm (8000 Å)
Range of angle of diffraction	0.145 to 0.344 rad 8.3 to 19.87°	0.308 to 0.665 rad 17.6 to 38.08°	0.384 to 0.488 rad 22.0 to 44.21°
Spectral order	1	1	1
Main Grating (servo driven to next set of spectral strips)			
Type	Echelle	Echelle	Echelle
Size	70.8 ×44.1 mm	121 ×45.7 mm	179 ×45.5 mm
Ruling frequency	209.96 lines/mm	472.4 line/mm	208.42 line/mm
Dispersion	10^{-11} m (0.1 Å)/mm at 0.3 μm (3000 Å)	10^{-11} m (0.1 Å)/mm at 0.5 μm (5000 Å)	10^{-11} m (0.1 Å) mm at 0.8 μm (8000 Å)
Range of angle of diffraction	1.19 to 1.296 rad (68.01 to 74.15°)	1.324 to 1.408 rad (75.58 to 80.5°)	0.385 to 0.773 rad (22.0 to 44.21°)
Number of images with 50 ea ten Å strips/image	In 4 images	In 8 images	In 10 images
Recorder characteristics			
Type	Imaging tube	Imaging tube	Imaging tube
Aperture (Recording format size)*	100 mm ×100 mm	100 mm ×100 mm	100 mm ×100 mm
Equivalent picture elements/image	2.5×10^7	2.5×10^7	2.5×10^7
Resolution	50 line pairs/mm	50 line pairs/mm	50 line pairs/mm
Equivalent bits per image	1.75×10^8	1.75×10^8	1.75×10^8
Weight	9 kg (19.8 lb)	9 kg (19.8 lb)	9 kg (19.8 lb)

*Up to fifty 100 mm × 2 mm spectral strips can be recorded at the same time per electronic imaging tube.

This will permit observing advancing and receding prominences and compensation for the orbital velocity of the telescope. The wavelength shift in both cases is caused by the doppler effect. The basic data registration camera is an imaging tube with an effective image size of at least 24 × 24 mm and a resolution of 56 TV lines per mm. (See Table 3-6.)

3.4.1.2.5 White Light Imaging. The white light camera will record data in various bands of the visible spectrum. For this a filter wheel will be incorporated with red, yellow, blue and polarizing filters. Neutral density filters will also be included as required, so that correct intensities will be obtained with each of the filters. The basic camera mechanism will be the same as that for hydrogen-alpha.

Table 3-6. Electronic Imaging Tube Camera Characteristics of 1.5-Meter Diffraction-Limited UV-Visible Normal-Incidence Solar Telescope

	H-α	WL	UV
Spectral Range, μm (Å)	0.6563±0.0002 (6563 ±2)	0.6 to 0.4 (6000-4000)	0.3 to 0.3 (3000-2000)
Resolution, m (arcsec)	10^{-11} (0.1)	10^{-11} (0.1)	10^{-11} (0.1)
Format (mm)	25.4 × 25.4	25.4 × 25.4	25.4 × 25.4
TV lines/mm	56	56	56
Frame Rate (fps)	0.1 to 0.1	0.1 to 1.0	0.1 to 1.0
Date Type	Analog	Analog	Analog
Passband (MHz)*	0.13 to 1.3	0.13 to 1.3	0.13 to 1.3

*Estimated bandwidth is based on using a 1900 TV lines per frame vidicon with an aspect ratio of 1 and a frame rate of 0.1 to 1 frames per second.

3.4.1.2.6 Ultraviolet Imaging. The ultraviolet camera will be a relatively broad-band device covering the region from 0.3 to 0.2 μm (3000 to 2000Å) or lower. This system will incorporate a UV-sensitive image tube and one or more Fabry-Perot interference type filters. The basic camera will be the same as for the hydrogen-alpha except for image tube spectral sensitivity.

3.4.1.2.7 Solar Magnetic Field Measurement. A magnetograph, a device for determining the intensity of the sun's magnetic field over a selected area of the solar disk,

is used to obtain magnetic field measurements simultaneously with other measurements, if possible. Several conceptual approaches are known, one utilizing line scanning and one using a filtered image. In each of these approaches the magnetic intensity is determined by measuring the splitting of spectral lines in the visible range resulting from the Zeeman magnetic effect, using polarization measurements to separate the Zeeman splitting from broadening of the lines. The first method requires line scanning of the desired portion of the surface of the sun. In the filter magnetograph concept a tunable narrowband filter is used to give a picture of the entire solar area at once. Space for two instruments is provided in the instrumentation section directly behind the photoheliograph primary mirror (Figure 3-2). (See Table 3-7 for three candidate approaches likely to be used with 1.5-m photoheliograph for magnetograph work.) The Doppler Zeeman approach is expected to enable measurements at various points in the spectrum and is free from saturation. The initial photoheliograph light output is split into two paths: one for the magnetographs and one for the other instruments. A flip mirror (light directive switch device) is used to route light to the magnetograph used. If light to the magnetograph is not sufficient for some of the short-time observations, the total 1.5-m solar telescope output may be switched to the selected magnetograph.

a. Line Scanning Magnetograph. One of the two magnetographs which may be connected to the 1.5-m photoheliograph telescope output light path is a line scanning instrument. The line scanning magnetograph is expected to be capable of solar magnetic field measurements with a sensitivity of $\Delta H = 10^{-5}$ to 10^{-4} telsa (0.1 to 1 gauss), together with 5×10^{-7} rad (0.1 arcsec) spatial resolution of the 1.5-m solar telescope. The time during which the area may be observed is variable from about one second to several hundred seconds depending upon the amount of information processing enhancement, angular field resolution, and magnetic field gradient resolution desired. The line scanning magnetograph instrument is about 0.5 m thick by 1 m wide by 5 m long due to the geometry needed for optics for collimation of the two (split) light paths, the use of a grating for band selection, and coupling to the imaging tubes. Refer to the second column of Table 3-7 for performance characteristics. The line scanning magnetograph functions are as follows:

The instrument obtains a resultant image or set of solar megnetic field data by differencing two images formed by light-scanning two light paths containing polarization components of the solar area (strip) being observed.

A real image of the sun is coupled from the 1.5-m solar telescope by a beam splitter and relay optics to the entrance slit of a high-dispersion spectrograph. Behind the entrance slit, a quarter-wave plate changes the circularly polarized light into linearly polarized light. After being imaged off the grating, the light is split by polarization optics into two separate beams and fed to two electronic

Table 3-7. Magnetograph Characteristics

PARAMETERS	(OPTION B) LINE SCANNING SPECTROHELIOGRAPH TYPE MAGNETOGRAPH	FILTER MAGNETOGRAPH	(OPTION A) DOPPLER ZEEMAN SPECTROGRAPH (SUBSTITUTE FOR LINE SCANNING MAGNETOGRAPH)
Desired Performance:			
Effective Field of View, rad (arcsec)	2.3×10^{-4} by 2.3×10^{-4} (46.8 × 46.8)	2.3×10^{-4} by 2.3×10^{-4} (46.8 × 46.8)	2.3×10^{-4} by 2.3×10^{-4} (46.8 × 46.8)
Effective Angular Resolution, rad (arcsec)	5×10^{-7} (0.1)	5×10^{-7} (0.1)	5×10^{-7} (0.1)
Number of Elements Observed	2.178×10^{5}	2.178×10^{5}	2.1×10^{5}
Magnetic Sensitivity, long., tesla (gauss)	$\Delta H = 10^{-5}$ to 10^{-4} (0.1 to 1) @ $S/N \approx 3300$	$\Delta H = 10^{-4}$ to 5×10^{-4} (1 to 5)	10^{-4} (1)
Magnetic Sensitivity, trans., tesla (gauss)			10^{-3} (10)
Effective Spectral Bandwidth, m (Å)	2.4×10^{-7} (0.05)	6.1×10^{-7} (0.125)	5×10^{-7} (0.1)
Minimum Quantum Efficiency	0.05	0.05	0.01
Estimated System Transmission	0.1	0.1	0.1
Equivalent Integration Time	Variable from 20 to 200 sec	10 sec	30 sec
Saturation Level, tesla (gauss)	1 (>10,000)	@ F_e, 0.525 μm ~0.15 @ F_e, 5250 Å (~1500); Other lines (~1) (~>10,000)	Unlimited
Polarization Assembly	1/4, 1/2 wave plates	KDP plate	1/4, 1/2 wave plates
Filter		Birefringent Filter or Fabry-Perot (Ramsey Type)	
Wavelength Region, μm (Å)	0.5 (5250)	0.5 (5250)	6.6 to 11.1 (6000 to 11,100)
Bandwidth, m (Å)	5×10^{-12} (0.05)	5×10^{-12}, 1.25×10^{-11}, 3×10^{-11}, 6×10^{-11} (0.05, 0.125, 0.3, 0.6)	10^{-12} (0.01)
No. of Frames Simultaneously Recorded	2 (one of each polarization)	1	4
Line Scanning (Shifting Slit Position/ at same time)	468 lines per 0.02 sec	—	468 lines per 0.05 sec
Number of Light Paths	2	1	4
Number of Frames Per Second	50	60	20
Differencing of Frames from Multiple Tubes	Yes	Yes	Yes
Quick Access Storage 2 Frames for Processing + 2 Frames for next Recording	8.712×10^{6} bits	8.712×10^{6} bits	100 × 16 bits
Processing Time, sec	0.04	0.033	30
Resultant Frame Rate	25 frames/sec (from previous parts)	30 frames/sec (from previous parts)	—
Desired Storage for Averaging	25 frames (5.46×10^{7} bits)	30 frames (6.534×10^{7} bits)	$2.178\times10^{5}\times16\times4$ bits
Total Storage for Processing, bits	$\sim7.4\times10^{7}$	$\sim7.4\times10^{7}$	2.8×10^{7}
Resultant Image Data*	1 frame (2.178×10^{6} bits/sec)	1 frame (2.178×10^{6} bits/sec)	2 frames/min
Size, m (ft)	0.5 × 1 × 5 (1.64 × 3.28 × 16.4)	0.1525 × 0.458 × 0.915 (0.5 × 1.5 × 3)	0.5 × 1 × 5 (1.64 × 3.28 × 16.4)
Weight, kg (lb)	Desired: 181.5, max. 680 (400, max. 1500)	90.8 (200)	Desired: 181.5, max. 725 (400, max. 1600)
Power, watts	200	75	200

*Available once per 2 sec to 30 sec at associated supporting information processor output

imaging tubes. The electron beams of the image tubes scan along the slit, creating an effective exit slit. The outputs of the imaging tube may be digitized or kept in analog form as convenient for differencing the two output images. The differencing can be accomplished on a line-by-line basis or on an image-by-image basis, depending upon whether digital or optical correlator processing is utilized. For each pair of polarization component images, an equivalent resultant image set of data containing the magnetic field pattern and field strengths versus solar location is obtained. Ten to 25 successive resultant magnetic field patterns may be statistically processed or averaged to form an enhanced magnetic field pattern. One enhanced magnetic field pattern versus solar location is obtained for each desired observation period (of 1 second to 200 seconds duration). If the observation period is short (1 sec) and 50 raw image sets of data are digitized for processing, the equivalent input data rate may be as high as 1.09×10^8 bits per second. However, if some form of line-by-line or image-by-image differencing is provided at the output of the two imaging tubes, the maximum input data rate may be reduced to 5.45×10^7 bits per second. Since the time for line scanning is variable, the data rate may be further reduced by a factor of 200. However, the average values obtained may not indicate the ambient state of the magnetic field as accurately as a shorter time period.

b. Filter Magnetograph. The second of the two magnetographs is a filter-type instrument which obtains successive images of a 2.3×10^{-4} by 2.3×10^{-4} rad (46.8 by 46.8 arcsec) area of the sun through a polarization "analyzed," very narrowband light path. (See third column of Table 3-7 for performance parameters.) The optical light path from the selected area on the sun passes through the 1.5-m solar telescope to a light-splitting device which provides a light beam to the magnetographs as well as to the echelle spectrographs and other instruments. A light diverter (flip or switch) mirror couples the light path to the filter magnetograph aperture stop through which the 2.3×10^{-4} by 2.3×10^{-4} rad 46.8 × 46.8 arcsec) portion of the selected solar area image passes. After the aperture stop, an enlarging lens is utilized to couple the image to a 1/4-wave plate (which may be flipped 180°) or to a KDP crystal. The polarization device enables analysis of the alternate images. The polarization-affected images then pass through a birefringent filter of 1.25×10^{-11}m (0.125 Å) bandwidth or through a Ramsey-type Fabry-Perot filter of 6×10^{-12}m (0.06Å) bandwidth to an electronic image tube unit, such as a 38 mm (1.5 inch) O.D. SEC vidicon with a 1000 line pair imaging capability on a 25.4 × 25.4 mm format. However, only about 468 lines will be recorded per image at a maximum imaging rate of 60 frames per second. Alternate images will be read into rapid-access storage from which they will be extracted for differencing in a local information processor while the next two images are being recorded in adjacent storage. Each image contains about 2.178×10^5 elements with intensity digitized to 10 bits,

giving about 2.178×10^6 bits per image. Hence, about 1.087×10^7 bits of rapid-access storage is needed for differencing the successive alternate polarization-affected images. A resultant image of about 2.178×10^6 bits of information will be obtained from the differencing process about once per 0.033 second. At 30 resultant frames per second, the quick access storage to enable statistical processing or averaging of a typical data set of 10 to 30 frames will be about 6.534×10^7 bits. It is expected that an equal reserve for the next set of data will be required if processing occurs while continuing observations. The local information processor extracts the desired number of frames from the statistical portion of the memory to obtain one equivalent magnetic field pattern, of about 2.178×10^5 bits per second. Resultant patterns may be obtained at 10 to 20 second intervals to track magnetic field pattern changes.

c. Doppler Zeeman Magnetograph. As an alternate to the line scanning magnetograph, a third type of solar magnetograph could be installed in the same size space as the line scanning magnetograph. This magnetograph obtains the magnetic field strength by a direct measurement of the Zeeman splitting of the line. This type of measurement would be less sensitive to temperature variations on the sun and could be extended to measure the magnetic field strength in the chromosphere of the sun. In addition, the vector magnetic field could be obtained by extended computations on board the spacecraft. A total magnitude field picture of a 2.3×10^{-4} by 2.3×10^{-4} rad (46.8 by 46.8 arcsec) area would take 30 seconds to complete, giving a data rate of 1×10^7 bits/sec. A sensitivity of 10^{-4} telsa (1 gauss) might be obtainable.

3.4.1.3 Observation/Measurement Program

3.4.1.3.1 Operations. Simultaneous imaging, spectroscopy, and correlated observations of solar phenomena are to be accomplished versus each selected area on the sun by the photoheliograph and its associated instruments. Operation will be continuous to the extent possible in the available orbits and supporting vehicles. Until adequate data recording and transmission capability is developed during the life of the instruments, it may be necessary to limit the number of observations per orbit or time period.

A typical operating cycle for a set of time-correlated (simultaneous) measurements is given on the following page.

	Duration (min/cycle)	Number of Cycles
(1) <u>Dark-Side-of-Orbit Operations</u>		
(Preparation for Solar Observation)		
a. Observation area selection	5	1 per orbit
b. Previous light side data transmission (if any)	Dark Period	1 per orbit
c. Remotely controlled photoheliograph & instrument alignment & adjustment	10	1 per orbit
d. Offset reference star & pointing sequence selection and computations	5	1 per orbit
e. Preorientation in sun direction	10	1 per orbit
(2) <u>Light-Side-of-Orbit Operations</u>		
a. Acquisition of reference guide stars	1	1 per orbit
b. Location of selected observation area with stellar inertial reference support	1	1 per orbit
c. Focus on selected observation area (with aid of white light monitor)	1	1 per orbit
d. Simultaneous observation of selected solar area; obtain following per selected area:	0.33	1 per orbit
(d-1) Echelle spectroscopy for complete set of images	Included above	
(d-2) Hydrogen-alpha images correlated with selected spectral images at rates from 0.1 to 1 frame/sec	Included above	
(d-3) White light images correlated to time with above	Included above	
(d-4) Ultraviolet images correlated to time with above	Included above	
(d-5) Magnetograph data correlated with above	Included above	

	Duration (min/cycle)	Number of Cycles
e. Total reference star location plus observation unit cycle (a through d)	3.33	1 per area
f. Repeat above observation cycle, if data handling capability remaining & continued observation desired on same spot	0.33	Continual as desired
g. Repeat location, focus, & observation cycle if new location desired (b+c+d) and if data handling capability remaining	2.33	per next area
h. Continue simultaneous or fractional operations if data handling capability & solar view remaining	Up to 45	as available
(3) At beginning of dark side of orbit, repeat preparation cycle (1) for next or same selected site. Note: Approximately 17 min. of orbit dark side exists for contingencies in 55°, 500 km (270 n. mi.) orbit; more for high-altitude orbits.	30	

3.4.1.3.2 Periodic Maintenance Activities. Maintenance operations as well as periodic deployment cycles are dependent on failure rate (reliability) and maintainability of the experiment equipment. Based on the following predictions, maintenance of the module is necessary only about once per 1/2 year, and possibly only once per year. Onboard automatic checkout would be activated once per 24 hours.

	Duration (hours/cycle)	Number of Cycles
a. Reliability		
Max operating time per 180 days	4320	Data continual
Max failures per 180 days	0.480	Random

	Duration (hours/Cycle)	Number of Cycles
b. Maintainability		
Total unscheduled maintenance down-time & crew time per 180 days (clock hours)	1.48	Random
Total scheduled maintenance down time and crew time per 180 days (clock hours)	12.0	1 per 180 days
Total maintenance crew time per 180 days	13.5	1 per 180 days

3.4.1.4 Photoheliograph Interface, Support and Performance Requirements

3.4.1.4.1 Basic Photoheliograph Requirements on Supporting Vehicle. Table 3-8 contains a summary of experiment interface, support and performance requirements for the 1.5-m photoheliograph and representative instruments likely to be utilized at the focus.

3.4.1.4.2 Data Processing, Handling and Communication Requirements. All-electronic imaging is desired where possible. Film is an alternate option for continual solar observations. Since the objective of the photoheliograph and its associate representative instruments is to obtain a maximum amount of time-correlated detailed spectral and spatial information about selected areas of the sun, simultaneous data output from the instruments can approach several thousand megabits per second. However, the data can be fed in parallel in many parallel channels to load data-processing or data-storage units. (Each channel may have a number of parallel lines to reduce the data rate per hard line.)

It appears difficult with the present state of the art to obtain a complete set of time-correlated information from all the available sensing instruments in a desired one-second period by 1976. The one-second period corresponds to a nominal period where large change of an observed spot on the sun occurs infrequently. Where such changes do occur, the equipment might be operated in a snapshot mode where sensor exposures occur for small equivalent exposure times (0.1 sec or less) at one- or two-second intervals for several cycles.

For an example of the partial spectral coverage obtainable during a single exposure, as well as a complete spectral sequence or data set, refer to Table 3-9.

Table 3-8. 1.5 Meter Photoheliograph Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Telescope Focus and Alignment	b. Observation Area Location	c. Echelle Spectroscopy	d. H-α Granular Motion Measure.	e. White Light High Resolution Imaging	f. Ultraviolet Imaging	g. Solar Magnetic Field Measurement		ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	1.5 M Telescope Alignment Scope White Light Monitor	1.5 M Telescope or Spotting Scope White Light Monitor	1.5 M Telescope Echelle Spectrograph Assembly	1.5 M Telescope H-α Camera	1.5 M Telescope White Light Camera	1.5 M Telescope UV Camera	1.5 M Telescope Magnetographs (2)		a, b, c, d, e, f, g in sequence	c+d +e+ f+g simultaneous
Launch Mass, kg (Weight, lb)										2082 (4590)
Logistics Support										
Consumables, kg/180D† (lb/180D)	1.4 (3)	1.4 (3)	386 (850)	16 (35)	32 (70)	16 (35)	1.8†† (4)		454 (1000)	4540 (10,000)
Spares, kg/180D (lb/180D)	10 (22)	5 (11)	10 (22)	10 (22)	10 (22)	10 (22)	20 (44)		75 (165)	
Crew Support										
Initial Setup, Manhours/180D	4									4
Periodic Serv. & Maint., Manhours/180D	13.5								13.5	13.5
Operation, Remote Control, Manhours/Observation Cycle	1 Man, 0.2 hr/ 90 min.	1 Man, <0.1 hr/ Spot.	1 Man, 0.01 hr to 0.75 hr	1 Man, 0.01 hr to 0.75 hr	1 Man, 0.01 hr to 0.75 hr	1 Man, 0.01 hr to 0.75 hr	1 Man, 0.01 hr to 0.75 hr		0.3 hr to 0.75 hr	0.3 hr to 0.75 hr per 90 min
Electric Power:										
Peak Load, Watts	435, 245*	195	215	175	175	175	200		Max 435**	245** peak
Average Load, Watts			215	175	175	175	175		175 to 215	215
Standby Load, Watts	-175	165 + 10	175	175	175	175	175		75	175
Environmental Control										
Desired Vehicle Heat Sink Temp, °K									263 to 313	
Temp. Limits, Stowed, °K										
Temp. Range, Ops., °K	291 to 297	291 to 297	291 to 297	291 to 297	291 to 297	291 to 297	291 to 297		291 to 297	291 to 297
Max. Temp. Difference, °K	±2	±2	±2	±2	±2	±2	±2		±2	±2
Relative Humidity, %	<40	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		<40	≃0
Atmosphere Limit, N/m^2 Torr	0 to 10^5 (0 to 15) psi	1.33×10^{-5} (10^{-7} Torr)	1.33×10^{-5} (10^{-7} Torr)	1.44×10^{-5} (10^{-7} Torr)	1.33×10^{-5} (10^{-7} Torr)	1.33×10^{-5} (10^{-7} Torr)	1.33×10^{-5} (10^{-7} Torr)		1.33×10^{-5} (10^{-7} Torr)	1.33×10^{-5} (10^{-7} Torr)
Cleanliness Class	Better than 100,000	100,000	10,000	100,000	100,000	10,000	10,000		100,000	10,000
Gravity Level, Max. g	$<10^{-4}$ (Avoid Flexure)	10^{-3}	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-4}		10^{-4}	10^{-4}
Radiation Sensitivity, millirad/hr	<1	-	-	-	-	<1	-		-	<1
Contamination Sensitivity	Yes		Yes	-	-	Yes	Yes		Yes	Yes

* Transient of heaters to operate power on dark side may be avoidable.
**Heater Load to compensate for radiation loss on dark side.
†If film utilized; Cassettes would be exchanged at least once each 30 days or as required by effect of accumulated radiation on film.
††End result images only after local information processing.

Table 3-8. 1.5 Meter Photoheliograph Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Telescope Focus and Alignment	b. Observation Area Location	c. Echelle Spectroscopy	d. H-α Granular Motion Measure.	e. White Light High Resolution Imaging	f. Ultraviolet Imaging	g. Solar Magnetic Field Measurement		ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	Sun Synchronous	Sun Synchronous	Sun Synchronous	Sun Synchronous	Sun Synchronous	Sun Synchronous	Sun Synchronous		-	Sun Synchronous
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0		55 to 0	-
Desired Altitude, km	500	500	500	500	500	500	500			500
(n.mi.)	(270)	(270)	(270)	(270)	(270)	(270)	(270)			(270)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740		370 to 740	
(n.mi.)	(>200 to 400)	(>200 to 400)	(>200 to 400)	(>200 to 400)	(>200 to 400)	(>200 to 400)	(>200 to 400)		(>200 to 400)	
Orientation:										
Observed Object Location	Bright Star	Sun	Sun	Sun	Sun	Sun	Sun		Bright Star/Sun	Bright Star/Sun
Observed Object Brightness, mag., m_v	-2.5 to 1	Sun	Sun	Sun	Sun	Sun	Sun		Bright Star/Sun	Bright Star/Sun
Observation Field of View, rad	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	3.2×10^{-4}		3.4×10^{-4}	3.4×10^{-4}
(arcmin)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)	(1.1)		(1.1)	(1.1)
Pointing Accuracy, rad	5×10^{-6}	5×10^{-6}	Des: 5×10^{-7} (0.1)	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}		1.2×10^{-5}	5×10^{-7}, 5×10^{-6}
(arcsec)	(1)	(1)	Acc: 1.2×10^{-5} (2.5)	(1)	(1)	(1)	(0.1)		(2.5)	(0.1, 1)
Pointing Stability, rad/obs time	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}	2.4×10^{-7}		2.4×10^{-7}	2.4×10^{-7}
(arcsec/obs time)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)		(0.05)	(0.05)
Slew Rate, max., rad/sec	-	5×10^{-5}	-	-	-	-	-		-	5×10^{-7}
(arcsec/sec)	-	(10)	-	-	-	-	-		-	(1.0)
Slew Rate, min., rad/sec	-	5×10^{-7}	-	-	-	-	-		-	5×10^{-7}
(arcsec/sec)	-	(0.1)	-	-	-	-	-		-	(0.1)
Pointing Hold Time, sec	Up to 900	Varies	60 to 2700	60 to 2700	60 to 2700	60 to 2700	60 to 2700		Up to 2700	Up to 2700
Data Requirements/Observation Cycle:										
Number of data sets/orbit	1	1	2	10	10	10	2***		2 to 10††	20 to 100††
Imaging Data										
Desired Resolution (spatial, spectral, magnetic)	5×10^{-7} rad (0.1 arcsec)	2.4×10^{-7} rad (0.05 arcsec)	2×10^{-13} m (0.002 Å) 5×10^{-7} rad (0.1 arcsec)	5×10^{-7} rad (0.1 arcsec)	5×10^{-7} rad (0.1 arcsec)	5×10^{-7} rad (0.1 arcsec)	10^{-5} to 5×10^{-4} tesla 0.1 to 5 gauss 5×10^{-7} rad (0.1 arcsec)		2×10^{-13} 0.002 Å 5×10^{-7} rad (0.1 arcsec)	2×10^{-13} 0.002 Å 10^{-5} to 5×10^{-4} tesla 0.1 to 5 gauss 5×10^{-7} rad (0.1 arcsec)
Equiv. Image Format Size, mm	25.4 × 25.4	25.4 × 25.4	100 × 100	25.4 × 25.4	25.4 × 25.4	25.4 × 25.4	24.5 × 24.5			
Picture Elements/Image (Data Set)	2.756×10^5	2.756×10^5	$3(2.5 \times 10^7)$	3.6×10^5	3.6×10^5	3.6×10^5	2.178×10^5		2.5×10^7	(1.14×10^8)
Images/Data Set	-	-	22	2	4	2	30 pairs**		2 to 82	90
Images/Second	30	30	0.1 to 1	0.1 to 1	0.1 to 1	0.1 to 1	0.1 to 1***		0.1	0.1 to 1
Photometric Resolution, %, bits	7	7	7	7	7	7	10		1 to 0.1% or 7 to 10	7 to 10
Equiv. Analog Data, MHz	2.9	2.9	-	0.13 to 1.3	0.13 to 1.3	0.13 to 1.3			2.9	4.2
Equiv. Digital Data, bits/image	-	-	$(1.75 \quad 10^8)$ 22	†	†	†	1.34×10^8		7×10^8	4×10^9
Non-Imaging Data: Command Data, bps										Combined data sets
Science/Exp. Data, bps	300	300	900	300	300	300	300		300	2100
Housekeeping Data, bps	400	400	2700	900	900	900	900		900	5300
Special Requirements:										
Updating Cycle, Years	2	5	2	2	2	2	2		2	2
Mass, kg/yr (Weight, lb/yr)	9.1 (20)	9.1 (20)	27.2 (60)	9.1 (20)	9.1 (20)	9.1 (20)	27.2 (60)		100 (220)	100 (220)
Volume, m^3/yr (ft^3/yr)	2.83×10^{-2}	2.83×10^{-2}	8.5×10^{-2}	2.83×10^{-2}	2.83×10^{-2}	2.83×10^{-2}	8.5×10^{-2}		0.311	0.311
	(1)	(1)	(3)	(1)	(1)	(1)	(3)		(11)	(11)
Local Info Processing							Required		Required	Required
Alternate Imaging Option:										
Film Width, mm	35	35	120	35	35	35	35		-----	
Film/orbit, cm (in)	3.5 (1.38)	3.5 (1.38)	527 (210)	70 (27.6)	140 (55)	70 (27.6)	7 (2.76)			

†May be converted to digital for improved perf.
††Combined data sets
†††Imaging data parameters represent (hardware) inputs to local processing, not output data transmission rate.

**In 1 sec for magnetograph
***End-result images after local processing

Table 3-9. Echelle Spectrograph Assembly Estimated Data Output

	RANGE 1	RANGE 2	RANGE 3
Spectral Band	0.3 μm to 0.13 μm	0.7 μm to 0.3 μm	1.1 μm to 0.6 μm
Band Extent	0.17 μm	0.4 μm	0.5 μm
	(3000 Å to 1300 Å)	(7000 Å to 3000 Å)	(11,000 Å to 6,000 Å)
	(1700 Å)	(4000 Å)	(5,000 A)
Desired Spectral Resolution	2×10^{-13}m (2×10^{-3} Å)	2×10^{-13}m (2×10^{-3} Å)	2×10^{-13}m (2×10^{-3} Å)
Spectral Dispersion	5×10^{-7}m/mm (0.1 Å/mm)	5×10^{-7}m/m (0.1 Å/mm)	5×10^{-7}m (0.1 Å/mm)
Spectral Strip Length	17,000 mm	40,000 mm	50,000 mm
Number of Strips, 100 mm long	170	400	500
Number of Strips, 2mm high on 100 x 100 format	50 strips per image	50 strips per image	50 strips per image
Number of Standard Frames	4 images*	8 images	10 images
Elements/Image**	5000 x 5000 = 2.5×10^7/ image	5000 x 5000 = 2.5×10^7/ image	5000 x 5000 = 2.5×10^7/ image
0.1% Photometric Rel. Accuracy	7 bits	7 bits	7 bits
Bits per Image	1.75×10^8	1.75×10^8	1.75×10^8
Number of Images/Data Set	4	8	10
Total Data per 3 Range Spectrum Set	7.0×10^8	$+1.4 \times 10^9$	$+1.75 \times 10^9$
Desired Recording Rate 1 image/sec	1	1	1
Acceptable Recording Input Rate, image/sec	0.1	0.1	0.1

Total data per spectral set = 3.85×10^9 bits in 10 sec.

* Requires use of full standard frame; 3.4 actually required.

**Assumes linearly spaced light-sensitive cells in matrix type mask on image input face of echelle registration device with at least 50 line pairs resolution.

The interface requirements portion of Table 3-8 shows instrument data output parameters (storage or data processor input data) in modular increments for a single set of equivalent images. The desired data output is totaled under desired simultaneous operation in the last column of the table. Until sufficient operational capability of the instruments, onboard data processing, data storage, and supporting data transmission links is developed by assigned supporting vehicle and network activities, only partial simultaneous combinations of data can be obtained. Hence, only partial spectral and time correlation of phenomena can be expected, but substantial experimentation toward simultaneous solar information acquisition can be completed.

One of the suggested interim solutions for the echelle spectrograph output is to record at 175 megabits/sec in 3 erasable rapid-access memories (disk or drum recorders). If limited to one spectral set per orbit, total elapsed recording time is 10 to 15 sec. Playback time is 80 minutes (4800 sec). Resultant data transmission rate is $3.85 \times 10^9/0.48 \times 10^4 = 8 \times 10^5$ bits/sec, or, if played back in 10 minutes, is $3.85 \times 10^9/0.6 \times 10^3 = 6.4 \times 10^6$ bits/sec. When single observations are conducted there will be a loss in correlatability and time-variant characteristics of the output information.

The eventual goal in operation of the photoheliograph, associated experiments, data processing, supporting vehicle, and information transmission networks is to obtain simultaneous coverage by all the instruments of the desired observation area on the sun at one-second intervals on a continual basis; such capability appears to be dependent on development of onboard data processing techniques, with only the significant information or changes being transmitted back to earth.

As may be noted in Table 3-8, the resultant data rate for simultaneous photoheliograph observation made at one-record intervals could be as large as 4 billion bits per sec. Consequently, one of the options indicated in this document is that of recording on film. For an average orbit between 28° and 55° inclination at about 500 km (270 n. mi.), a nominal data-taking profile as indicated in the number of data sets per orbit has been selected to limit the amount of film (about one equivalent data set per 180 seconds for images of the selected solar area and 1 spectrographic data set per 900 seconds). From the nominal data-taking rate, a typical film usage rate was derived for acceptable support as indicated under consumables in the logistics support portion of Table 3-8. A data-taking rate approximately ten times faster was also considered (one spectrographic data set per 18 seconds and solar images at one image-data set per 2 seconds. This faster rate results in the desirable support value for film, which may be more difficult to support. The 100×100 images were placed on 120-mm-wide roll film of 25.4 g/m (0.017 lb/ft) average mass.

The 25.4×25.4 mm images were assigned to 35 mm film at about 6.92 g/m (0.005 lb/ft) average mass. Allowance was also made for reels such that sensitive film would not be exposed in the film feed and takeup systems for more than about 8 days.

Bulk data processing was also considered at the reduced data sampling rates as a means for avoiding film holders and feed and takeup mechanisms. If a complete data set were to be acquired and read out to a parallel high-speed processor about once each 10 seconds, the resultant readout rate would be about 400 Mbs. Review of recently developed data processing strategies and techniques for spectrometry and magnetograph data indicates that a 50 to 100 equivalent data compression factor may be achieved if appropriate high-speed processors can be obtained. Such extraction of the resultant data from the raw data would then result in about 4 Mbs of data for the photoheliograph experiments in a most useful format to be transmitted to solar experiment control centers.

Magnetograph experiments with requirements for a series of pairs of polarization-component-affected images are expected to require near real-time comparison and statistical information processing support to enable reduction of resultant data to a manageable output quantity.

3.4.1.5 Potential Role of Man. Setup and maintenance requirements are summarized for this instrument in Section 3.4.1.3.2. Man's utilization in the operation of the instrument is considered necessary due to need for capability for selecting magnified areas on the solar disk, since all of solar disk is not covered by the 3.2×10^{-4} rad (1.1 arcmin) field of view. Automatic adjustment equipment with remote-control manual override is employed where practicable, but man sets adjustment ranges.

3.4.1.5.1 Deployment. Most, if not all, deployment is automatic. The sun sensor is erected and the mirror, gratings, and cameras are uncovered. The spectrographs (with their cameras), monitoring cameras, and spotting scope are premounted (that is, before launch) on the instrument support structure. The magnetograph may be premounted or may require manned in-orbit mounting, depending on the ruggedness and size of the final instrument design.

3.4.1.5.2 Focus and Alignment. Automatic focus and alignment capability with manned override is provided. However, a description is given of the manual backup mode. The direction and amount of the secondary mirror misalignment is indicated on a display meter, so the monitoring crew by remote control can use the servomotors to realign the mirror. Using an "A" scope, which displays a single television-line scan as an intensive time function, the crew will focus the camera position to maximize the edge sharpness and high-frequency video content. The position of the spot corresponding to optimum alignment will be established under ambient conditions. It is expected that this procedure will be performed by the Space Station or ground

control crew, by remote control during observations. The automatic focus and alignment, operating on telescope internal references, will maintain focus and alignment despite some thermal excursions of the telescope.

Alternatively, an optical technician observes a TV screen to interrupt a display of bright reference star images. A TV camera takes the place of the eye-piece of an autocollimator which is rigidly attached to the instrumentation support structure. The autocollimator is used in two modes. In the first mode, it projects an image which is reflected off the rotatable mirror (optical switch), then off an optically flat area on the center of the secondary mirror, and then reflected back through the system. If the projected and reflected images are in coincidence (in the manner of a rangefinder) then the secondary mirror is centered and normal to the telescope optical axis. The remote control operator or technician manipulates servomotor controls whose signals are transmitted to achieve this alignment. In the second mode, the autocollimator (with its image projector off) is used as an alignment telescope. The technician views the star image (on the monitor) and further adjusts the controls until he obtains the best possible star image shape on the monitor. As mentioned before, an automatic optical-tooling-type compensation device maintains alignment and focus during observations.

3.4.1.5.3 Calibration. Calibration will require a number of image sets with each of the three echelle spectrographs. Some of these may be test plates taken during alignment. The Lyot filter used in the chromospheric experiments is checked to be sure that it is centered on 6,563 Å.

The spectrograms are transcribed at the remote control point onto film and are ex-examined with a densitometer. (Alternatively, the echelle spectrographic data in digital format may be analyzed by computer routines of a selected point in the information chain.) Lyot and Fabry-Perot filters are calibrated with the help of a standard source or lamp.

The crew will calibrate and check the magnetograph measurement process and equipment periodically, particularly where several experiments share equipment.

3.4.1.5.4 Operation. The Space Station or ground control crew will play a very important role in this experiment by optimizing system performance during data-taking sequences. By use of computer-controlled coordinates, the spotting scope, and photoheliograph remote control, the observation crew can choose the solar region to be observed. The crew will be required to align and focus the optical components while on orbit, monitor the primary data in real time to evaluate system performance, and make the required adjustments and repairs to keep the system operating properly.

During normal operation after observation-area location, the experiment will operate automatically and the crew will be required to monitor the experiment periodically.

In event of failures (announced by appropriate alarms) which prevent automatic operation, the crew will control the experiment manually until repair can be made. In the manual mode the crew will be involved continually during observation periods. Until supporting vehicle onboard processing capability to handle simultaneous data inputs is achieved, crew operation is desired to select data sets.

3.4.1.5.5 Crew Interface. Either the Space Station crew or the ground control crew will utilize controls and displays connected by communication links to remotely adjust and operate the photoheliograph equipment. The following photoheliograph controls and displays are expected:

Focus/Alignment - Control/Display	Loyt Filter Tuning
Instrument Power - Control/Display	Camera Frame Rates (6)
Spotting Scope - Control/Display	Thermal Control - Control/Display
Grating Position - Control/Display	H-α Camera - Control/Display
Spectrograph Selection - Control/Display	UV Camera - Control/Display
Spectrograph Camera Exposure Times (3)	WL Camera Filter Position
Filter Temperature - Display	"A" Scope
Solar Heat Dump Control	Magnetograph - Control/Display

3.4.1.6 Available Background Data

a. Orbital Astronomy Support Facility (OASF) Study, Volume III, Task B, Instruments for Orbital Astronomy

b. A Long Range Program in Space Astronomy, Position Paper of the Astronomy Missions Board, NASA SP-213, July 1969.

3.4.2 XUV SPECTROHELIOGRAPH EXPERIMENTS

3.4.2.1 Scientific or Technical Objective. The XUV spectroheliograph is used to record the image of the solar disk in the various bright-line wavelengths between 1.7×10^{-8}m (170 Å) and 6.5×10^{-8}m (650 Å). A resolution of 5×10^{-6} rad (one arcsec) over a field of view of 8.7×10^{-3} rad (30 arcmin) is expected. To achieve satisfactory images in the extreme ultraviolet, very effective rejection of the lower wavelengths, which predominate in solar radiation, is desired.

3.4.2.2 Description. A spectrum selector assembly and a multispectral imaging camera assembly are used to obtain images at selected XUV spectral lines.

3.4.2.2.1 Focus and Alignment. The astronomer/controller operating the equipment remotely will utilize a monitor imaging camera to enable focus and alignment adjustments. The camera has the following characteristics and auxiliary optics to enable quick control of telescope and grating focus and diffraction angle and adjustments (final alignment of selected XUV spectral line images is accomplished by means of an electronic solar disk or spot imaging camera):

Format (image size) = 25.4 mm $\times$ 25.4 mm

Effective image resolution = 70 lines/mm

Picture elements/image = 3.24×10^6

Image (frames)/sec = 1

Effective angular adjustment resolution = 5×10^{-6} rad (1 arcsec)

NOTE: The monitor imaging camera also may be switched to alternate sweep circuits to give 525-line resolution/frame (20 lines per mm) at 30 frames/sec to enable coarse adjustments by remote control; however, effective angular resolution is only 1.65×10^{-5} rad (3.4 arsec).

The XUV field of view is to be capable of being stopped down or adjusted to match the field of view of the photoheliograph. Additional optics may be required.

3.4.2.2.2 Observation-Area Location. Since the XUV spectroheliograph axis is parallel to the 1.5-m photoheliograph axis in the assembly, the observation-area location process is similar to that for the photoheliograph.

3.4.2.2.3 Multiple XUV Imaging. A solar disk or selected solar location spot image is to be recorded at several selected XUV (brightline) wavelengths on one or more image-intensifier storage tubes. Each electronic imaging camera will have at least the performance indicated in Table 3-10 and will receive three adjacent images at different wavelengths. The spectrum selector (grating control) assembly characteristics for producing the multiple images is given in Table 3-11.

3.4.2.3 Observation/Measurement Program

3.4.2.3.1 Observation/Measurement Sequence. The typical observation/measurement program will parallel that for the 1.5-m photoheliograph. Images at several selected portions of the XUV spectrum will be obtained at the same time as images and spectroscopy in other portions of the solar output spectrum. A typical operations sequence is expected to be as follows:

Table 3-10. XUV Imaging Unit Characteristics

Basic image tube capability	5000 × 5000 elements
Combined image size	100 × 100 mm
Individual image size	27.9 mm diameter
Effective image resolution	50 lines/mm
Picture elements/combined images	2.5×10^7
Digital photometric accuracy (1%)	7 bits
Equivalent bits/combined frame	1.75×10^8
Exposure or registration time	1 sec
Readout time	10 to 100 sec
Effective data rate, bps	1.75×10^6

Table 3-11. Spectrum Selector Assembly

Wavelength	
Short	1.7×10^{-8} m (170 Å)
Long	6.5×10^{-8} m (650 Å)
	1.5×10^{-12} m (0.015 Å) at
Resolution	1.7×10^{-8} m (170 Å)
Entrance Aperture	No slit, aperture 0.25-m dia.
Incident Radiation	
f/No. Limitation	12, 24
Spatial Resolution	5×10^{-6} rad (1 arcsec)
Main Grating	
Type	Concave
Size	250-mm dia.
Ruling Frequency	3,333 lines/mm
Dispersion	10^{-10} m (1 Å)/mm at 1.7×10^{-8} m (170 Å)
Angle of diffraction range	3.3° to 12.5°
Spectral Order	1

	Duration (min/cycle)	Number of Cycles
a. <u>Dark Side of Orbit Operations</u>		
(Preparation for Solar Observations)		
1. Observation area selection*	5	1 per area
2. Previous-orbit light-side data transmission, if any	(dark side of inter-observation period)	
3. Remote controlled-XUV telescope checkout and alignment check & adjustment	10	1 per orbit
4. Offset reference star and pointing sequence selection & computations (same as in 3.4.1.3)	5	1 per orbit
5. Pre-orientation in sun direction (preparation time)	10	1 per orbit
	30 min	per orbit
b. <u>Light Side of Orbit Operations</u>		
1. Reference guide star acquisition	1	1 per orbit
2. Location of selected observation area	1	1 per orbit
3. Focus on selected area	0.5	1 per area
4. Simultaneous XUV imaging	(0.33)	1 set per area
5. Repeat (4) if continuing same spot observation	0.33	as desired
6. Total observation cycle time including reference star and location acquisition	2.83	1 per area
7. Operations cycle time, including selected observation area location	1.833	1 per area
8. Recommended dead time for other instrument synchronization	0.66	

*Accomplished at same time for photoheliographs, SUV spectroheliograph, and X-ray scope.

3.4.2.3.2 Periodic Maintenance Activities. Failure rates of the XUV spectroheliograph are expected to be about 0.48 per 180 days, indicating that actively manned maintenance may be necessary only about once per six months and possible only once a year. Table 3-12 shows an estimate of setup and maintenance requirements.

Table 3-12. Setup and Maintenance Requirements for 0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope

Operation	Average Times/ Year	Duration (hours)	No. of Men	Hours/ Man	Average Power (W)	Special Equip. Weight (lb)	Special Equip. Volume (ft^3)
Deployment	2	1/2	1	1/2	---	---	---
Focus & Alignment	(Remotely controlled, once per orbit)						
Calibration		1	1	1	3	---	---
Scheduled Maintenance	2	1.75	2	1	15	10	1
Unscheduled Maintenance	---	1	1	1	15	30	2

3.4.2.4 Experiment Interface, Support, and Performance Requirements. The 0.25-meter XUV spectroheliograph interface, support, and performance requirements with respect to a supporting space vehicle are defined in Table 3-13.

3.4.2.5 Potential Role of Man. Setup and maintenance time requirements are summarized for this instrument in Table 3-12. Man's utilization in the operation of the instrument is considered to be an emergency or backup mode as soon as an observation area is selected and operation is repetitive.

3.4.2.5.1 Preparation. Upon equipment arrival in orbit, an astronomer/astrophysicist will remove boost-phase protective equipment. The optics require only focusing in orbit. An astronomer/astrophysicist will inspect the equipment and image registration devices.

3.4.2.5.2 Calibration. A series of observations is made of the solar plages and inner corona, and then of some standard lamps. The two gratings are optimized for different wavelength regions, one for 170 and 650 Å and the other for 304 to 216 Å.

Table 3-13. XUV Spectroheliograph Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. 0.25 M Telescope Check, Focus, and Alignment (dk. side)	b. Observation Area Location	c. Multiple XUV Imaging						MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	XUV Telescope Alignment Source Monitor Camera	XUV Telescope (Optional Guiding Telescope) (Monitor Camera) Or Guided by 1.5-m image Monitor	XUV Telescope XUV Spectrum Selector (Slit Grating) XUV Multiple Imaging Camera						a, b, c	b + C
Launch Mass, kg (Weight, lb)										431 (950)
Logistics Support										
Consumables, kg/180D (lb/180D)	1.1 (2.5)	1.1 (2.5)	90 198						92 (203)	920 (2030)
Spares, kg/180D (lb/180D)	10 (22)	10 (22)	20 (44)						40 (88)	
Crew Support										
Initial Setup, Manhours/180D	0.5									0.5
Periodic Serv. & Maint., Manhours/180D	2.5	0.5	0.5							3.5
Operation, Remote Control, Manhours/Observation Cycle	0.05	0.05	0.05						~0.15 obs./cycle	0.05
Electric Power:										
Peak Load, Watts	70	70	60						70	70
Average Load, Watts	-	60	55						55	55
Standby Load, Watts	70	-	-						70	70
Environmental Control										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	253 to 309	253 to 309	253 to 309						253 to 309	253 to 309
Temp. Range, Ops., °K	290 to 294	290 to 294	290 to 294						290 to 294	290 to 294
Max. Temp. Difference, °K										
Relative Humidity, %	≤ 40%		< 10%						< 40%	< 10%
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 (0-15 psi acceptable)	1.33×10^{-5} (10^{-7} torr)	1.33×10^{-5} (10^{-7} torr)						0 to 10^5 (0-15 psi)	1.33×10^{-5} (10^{-7} torr)
Cleanliness Class	< 100,000	< 10,000	< 10,000						< 100,000	< 10,000
Gravity Level, Max. g	< 10^{-4} g (avoid flexure)	< 10^{-4} g (avoid flexure)	10^{-4} g (avoid flexure)						10^{-4} g (avoid flexure)	10^{-4} g (avoid flexure)
Radiation Sensitivity, millirad/hr	1	1	1						1	1
Contamination Sensitivity	Yes	Yes	Deposit Absorption						Yes	Yes, Deposition

Table 3-13. XUV Spectroheliograph Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS \ EXPERIMENT	a. 0.25 M Telescope Check, Focus, and Alignment (dk. side)	b. Observation Area Location	c. Multiple XUV Imaging					MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:									
Desired Inclination, deg			Sun Synchronous						Sun Synchronous
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0					55 to 0	55 to 0
Desired Altitude, km	500	500	500						500
(n.mi.)	(270)	(270)	(270)						(270)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740					370 to 740	
(n.mi.)	(> 200 to 400)	(>200 to 400)	(>200 to 400)					(>200 to 400)	
Orientation:									
Observed Object Location	Bright star/sun	Sun	Sun					Bright star/sun	Sun
Observed Object Brightness, mag., m_v	-2.5	Sun	Sun					Bright star/sun	Sun
Observation Field of View	9.3×10^{-3} rad (32 arcmin)	9.3×10^{-3} rad (32 arcmin)	9.3×10^{-3} rad (32 arcmin)					9.3×10^{-3} rad (32 arcmin)	9.3×10^{-3} rad (32 arcmin)
Pointing Accuracy, rad	5×10^{-6}	1.2×10^{-5}	1.2×10^{-5}					1.2×10^{-5}	5×10^{-6}
(arcsec)	(1)	(2.5)	(2.5)					(2.5)	(1)
Pointing Stability, rad/obs time	2.4×10^{-7}	5×10^{-7}	5×10^{-7}					5×10^{-7}	2.4×10^{-7}
(arcsec/obs time)	(0.05)	(0.1)	(0.1)					(0.1)	(0.05)
Slew Rate, max., rad/sec	-	5×10^{-5}	-						
(arcsec/sec)		(10)						(10)	1
Slew Rate, min., rad/sec	-	5×10^{-7}	-						0.1
(arcsec/sec)		(0.1)							
Pointing Hold Time, sec	720	360	19.8 to 2700						19.8 to 2700
Data Requirements/Observation Cycle:									
Number of Data Sets/Orbit	1	1	10					1-10	100
Imaging Data									
Desired Resolution, (spatial or spectral)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec)	5×10^{-6} rad (1 arcsec)						5×10^{-6} rad (1 arcsec)
Equiv. Image Format Size, mm	25.4 x25.4	25.4 x25.4	100 x100					25.4 x 25.4	100 x100
Picture Elements/Image	-	3.24×10^{6}	2.5×10^{7}					2.5×10^{7}	2.824×10^{7}
Images/Data Set	-	-	1					1	1
Images/Second	30	0.1 to 1	0.1 to 1					0.1	1
Photometric Resolution, %, bits	-	1%, 7	1, 7					7	7
Equiv. Analog Data, MHz	2.9	2.9	-					2.9×10^{6}	2.9×10^{6}
Equiv. Digital Data, bits/image	-	-	1.75×10^{8}					1.75×10^{7}	1.75×10^{8}
Non-Imaging Data: Command Data, bps									
Science/Exp. Data, bps									
Housekeeping Data, bps	15	15	15					45	45
Special Requirements:									
Updating Cycle, Years	-	-	2						2
Mass, kg/yr (Weight, lb/yr)	-	-	36 (80)						36 (80)
Volume, m^3/yr (ft^3/yr)	-	-	0.11 (4)						0.11 (4)
Alternate Imaging Option:									
Film Width, mm	35	35	120						
Film/Orbit, cm (in)	3.5 (1.38)	3.5 (1.38)	120 (47.3)						

3.4.2.5.3 Operation. During normal operation the experiment will operate automatically except for remote monitoring by scientist/astronauts or ground based astronomers, and the crew will be required to monitor the experiment periodically. In the event of failures which prevent automatic operation, the crew will control the experiment manually via remote control until repairs can be made. In the manual mode the crew will be involved continually during observation periods.

Pointing guidance is monitored by the monitoring camera on the 1.5-meter photoheliograph since the XUV spectroheliograph axis is aligned to the photoheliograph axis.

3.4.2.5.4 Scheduled Maintenance. An optical technician inspects the optical surfaces for damage or deterioration. He also inspects the electronic imaging camera for possible degradation of sensitivity or resolution.

3.4.2.5.5 Unscheduled Maintenance. Unscheduled maintenance results primarily from failure of one of the camera mechanisms. In the case of a sun-sensor failure, a backup instrument is available already mounted and the repair can be postponed until a scheduled maintenance period.

3.4.2.6 Available Background Data

J. W. Weschsler, J. J. Tosching, H. L. Wolbers, and J. J. Gordan, Orbital Astronomy Support Facility (OASF) Study, Volume III, DAC-58143, 28 June 1968

3.4.3 X-RAY GRAZING INCIDENCE TELESCOPE EXPERIMENTS

3.4.3.1 Scientific Objectives. The objective of this X-ray telescope is to increase both the spectral resolving power and sensitivity of the X-ray telescopes by one or more orders of magnitude and to scan individually selected lines with a temporal resolution of seconds and spatial resolution approaching that available in visible light.

The experiment is designed to measure the solar X-ray spectrum (approximately 10^{-10} to 2.4×10^{9}m, or 1 to 24 Å) with a spectral resolution approaching the crystal diffraction limit, a spatial resolution of a few arcseconds, and a temporal resolution of one-tenth second. The specific objectives of the experiment are:

a. To study the spatial distribution of temperature and density of an active region of a flare, by observing the variation in line intensity and relative line widths and relative line intensities.

b. To determine the validity of the concept of thermal equilibrium, by comparison of ion and electron temperatures derived respectively from line widths and relative line intensities.

c. To observe rapid fluctuations in line intensities indicative of large-scale changes in the energy input.

d. To attempt to measure microscopic material movement by doppler-shift measurements.

e. To observe relatively weak lines to determine the coronal abundance of elements such as Na and Al, and to study higher-series members of the strong spectra for detailed comparison with theoretical predictions.

f. Determination of electron temperature and charge density in the corona at different solar latitudes, from near the equator out to the pole.

g. Observations to determine if there is a significant hot component in the background corona. (This could not be unambiguously studied by broadband photography because of the spectral proximity of lines, e.g., Fe XVII and O VIII, having a quite different temperature response.)

h. Observations to study possible local abundance variations, e.g., in the Fe:O or Ne:O ratios, by comparison of the active region and coronal disk spectra.

3.4.3.2 Description

3.4.3.2.1 Image Stabilization With Signals from Reference or Boresighted Optical Telescope. Use of angular jitter signals from a boresighted optical telescope and white-light image monitor camera enables high-resolution X-ray imaging. The angular jitter signals for solar X-ray work may have to come from offset reference star trackers which sense telescope body movement or vibration, as well as from the image of the solar area observed.

3.4.3.2.2 High-Resolution X-Ray Imaging/Low-Resolution Spectrometry. The X-ray imaging process uses the grazing-incidence telescope to form the solar image, an image intensifier-converter to condition the image for recording, an electronic imaging device to record the images, and a means to provide a visual display for the astronaut. An X-ray transmission grating will be used to obtain low-resolution spectroheliograms of active regions. A visible-light lens and fiducial marks will be used to determine experiment pointing and alignment. Automatic exposure control of the image recording device will be obtained by use of an X-ray scintillation detector which will measure the incident X-ray flux. Data on this instrument is shown in Table 3-14.

3.4.3.2.3 Proportional Counter Measurements of Spectral Energy Distribution. A proportional counter array is utilized at the focus of the X-ray telescope to obtain relative spectral energy distribution over the spectrum from 10^{-8}m to 2×10^{-10}m (100 Å to 2 Å). The counter will be inserted in sequence at the X-ray telescope focal plane.

Table 3-14. X-Ray Imaging Device Parameters for Image Converter Intensifier and Imaging Tube at Output

Option	A	B
Image Intensifier	(*)	(*)
Imaging Tube at Intensifier Output		
Type	Vidicon	Vidicon
Aperture, mm (in.)	14.6 (0.575)	19.1 (0.75)
Resolution, line pairs/mm	28	28
Equivalent picture elements	405×405 = 164,025	525×525 = 275,625
Number of images/sec	10	1 to 10
Equivalent picture elements/sec	1,640,250	2,756,250
1% photometric resolution, bits	7	7
For 1 image/sec, bps	1.148×10^6	1.930×10^6
For 10 images/sec, bps	1.148×10^7	1.930×10^7
Mass, kg (lb)	22 (88)	22 (88)

*Electrons emitted from X-ray image converter go through a channel plate multiplier and are registered on a light-emitting screen which is viewed by a visible-light imaging tube. Deflection plates are available for reducing image jitter; signals for jitter reduction come from an angular jitter-sensing device.

3.4.3.2.4 X-Ray Spectroscopy. The X-ray spectrometer is intended to improve significantly the spectral energy distribution derived from the proportional counter. It consists of a slit, a curved Bragg crystal, and a series of channel multiplier detectors. The detectors are arranged so that their apertures lie along the Rowland circle of the spectrometer. In this arrangement, the spectrometer serves as a crossed grating device with the crystal serving as the principal grating and the detectors, with the aid of pulse height analysis, as the order sorter. Crystal spectrometer characteristics are found in Table 3-15.

Table 3-15. X-Ray Spectrometer Characteristics for 0.5-m X-Ray Grazing-Incidence Solar Telescope

Type	Crystal Spectrometer
Wavelength	
Short	19^{-9} m (10 Å)
Long	2×10^{-9} m (20 Å)
Resolution	10^{-11} m (0.1 Å) at 10^{-9} m (10 Å)
Entrance Aperture	
Slit Width	250 μm
Slit Height	250 μm
Incident Radiation	
f/No. Limitation	10
Spatial Resolution	2.4×10^{-5} rad (5 arcsec)

3.4.3.3 Observation/Measurement Program

3.4.3.3.1 Observation/Measurement Sequence. The typical observation/measurement program for the solar X-ray telescope will parallel that for the 1.5-m photoheliograph. However, images or data output can be obtained only in sequence because only one instrument can occupy the position at the X-ray telescope focus at one time. Where the X-ray telescope is operated on the same vehicle with the 1.5-m photoheliograph, optical observation area location data and angular jitter stabilizing signals will be obtained from the 1.5-m photoheliograph optics. However, for solar work, such angular sensing of telescope observations may come from the offset star trackers. A typical operational cycle is expected to be as follows:

a. Dark Side of Orbit Operations (Typical inter-observation task load)

(Preparation for Solar Observations)	Time/Min
1. Observation area selection	5
2. Previous sequence data transmission	(Dark or inter-observation period)
3. Remote controlled X-ray telescope and associated instruments checkout sequence & alignment	10

		Time/Min
4.	Offset reference star and observation pointing sequence selection and computation	5
5.	Preorientation in sun direction	10

b. Light Side of Orbit Operations (Typical observation period)

1.	Reference guide star acquisition by supporting offset star trackers	1
2.	Location of selected observation area by associated viewing device and pointing guidance	1
3.	Focus on selected area	0.5
4.	X-Ray imaging on selected area, synchronize exposures to associated 1.5-meter and XUV exposure times	0.33*
5.	Shift to proportional counter at X-Ray telescope focus	0.33*
6.	Proportional counter measurements, synchronize in time with associated VL and XUV exposures, if possible	0.33*
7.	Shift to crystal spectrometer at X-Ray telescope focus	0.33*
8.	Readjust focus if necessary	0.33
9.	High-resolution X-Ray spectral measurements	0.33
10.	Estimated total cycle time including supporting reference acquisition and observation area location	4.5
11.	Estimated cycle time including time for selection of new observation location	3.5
12.	Estimated repeated observation cycle time on same observation area	2.5

*Design goal; shifting done between sets of synchronized exposures approximately 20 seconds apart.

The ultimate objective in developing X-ray telescope observation techniques is to obtain continual measurements of the sun, synchronized in time with other instrument observations. Such observations would be taken at carefully timed intervals to enable calculation of solar phenomena extent and rate of change versus time. Until local onboard data processing, storage, and communications techniques are developed to handle the total data output, operations scheduling will be limited by the capability available.

3.4.3.3.2 Periodic Maintenance Activities. Since failure rates and time for maintenance and servicing will affect the available time for observation, the following information is provided:

a. Expected failure rate: 0.967 failures/180 days.

b. Table 3-16 shows time expected per year for setup and maintenance activities.

Table 3-16. Setup and Maintenance Requirements for 0.5-m X-Ray Grazing-Incidence Solar Telescope

Operation	Average Times/ year	Duration (hr)	No. of Men	Hours/ Man	Average Power (W)	Special Equip. Weight (lb)	Special Equip. Volume (ft^3)
Deployment	---	1	1	1	---	25	4
Alignment	---	1/4	1	1	5	5	1
Calibration	---	2	1	2	15	15	2
Scheduled Maintenance	1 or 2	3	2	3	15	15	2
Unscheduled Maintenance	1	4	1	3	15	20	2

3.4.3.4 Experiment Interface, Support and Performance Requirements. Table 3-17 summarizes in matrix format the key interface and support requirements related to maximizing experiment performance. Data output of the instruments operated in conjunction with the 1.5-m photoheliograph and the XUV spectroheliograph is related to the observation measurement program shown in Section 3.4.3.3. Data taking may be limited to 10 1/20-sec exposures per observation, or two equivalent exposures, or data-taking periods about 10 to 20 seconds apart. Where real-time transmission to the Station or ground experiment points cannot be achieved, local supporting vehicle data storage versus correlatable timing and identification words is recommended.

3.4.3.5 Potential Role of Man. Setup and maintenance requirements are summarized for the instrument in Table 3-16.

3.4.3.5.1 Alignment. The grazing-incidence reflector surfaces are carefully aligned and centered in their structural unit on the ground, so that there will be a plane of best focus within the back-end assembly (focal plane is only approximately correct terminology). The alignment procedure then consists in positioning the back-end so

Table 3-17. 0.5-Meter X-Ray Telescope Experiment Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Image Stab. with Signals From Bore Sighted Optical Tel.	b. High Resolution X-Ray Imaging Low Res. Spect.	c. Proportional Counter Spectral Energy Dist.	d. 1 High Res. X-Ray Spectroscopy	e. (Additional Exp. Not Yet Defined)				ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	X-ray telescope Image converter/intensifier bore-sight aux. optical telescope Optical image jitter sensor Note: 2nd & 3rd items may come from asso. 1.5M photoheliograph*	X-ray telescope Signals from optical bore-sighted telescope Image converter/intensifier plus image recorder	X-ray telescope Proportional counter	X-ray telescope Crystal spectrometer	X-ray telescope Space reserved for additional instrument					
Launch Mass, kg (Weight, lb)										400 (880)
Logistics Support										
Consumables, kg/180D (lb/180D)	1.1 (2.5)	14 (30)	-- --	-- --					15 (33)	150 (330)
Spares, kg/180D (lb/180D)	10 (22)	10 (22)	10 (22)	15 (33)					45 (99)	
Crew Support										
Initial Setup, Manhours/180D	1									
Periodic Serv. & Maint., Manhours/180D	2 men, 3 hr 1 time/180 day									
Operation, Remote Control, Manhours/Observation Cycle	1 man for 0.25 hr remote control align. on dark side of orbit	1 man for 0.1 hr to max obs time	1 man for 0.1 hr to max obs time	1 man for 1 hr to max obs time					1 man for 0.55 hrs per observ. sequence	0.55 hours to max obs time
Electric Power:										
Peak Load, Watts	595	-	-	-						595
Average Load, Watts†	450	450	450	450						450
Standby Load, Watts	260	-	-	-						260
Environmental Control										
Temp. Limits, Stowed, °K	253 to 309	253 to 309	253 to 309	253 to 309					253 to 309	253 to 309
Temp. Range, Ops., °K	290 to 294	290 to 294	290 to 294	290 to 294					290 to 294	290 to 294
Max. Temp. Difference, °K	2	2	2	2					2	2
Relative Humidity, %	< 40	-	-	-					< 40	-
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 (0 - 15)	1.33×10^{-4} (10^{-6} torr)	1.33 to 10^{-4} (10^{-6} torr)	1.33 to 10^{-4} (10^{-6} torr)					0 to 10^5 (0 - 15)	1.33×10^{-4} (10^{-6} torr)
Cleanliness Class	100,000	10,000	10,000	10,000					100,000	10,000
Gravity Level, Max. g**	$\leq 10^{-4}$	$\leq 10^{-4}$	$< 10^{-4}$	$\leq 10^{-4}$					10^{-4}	$< 10^{-4}$
Radiation Sensitivity, millirad/hr	< 1	< 1	< 1	< 1					< 1	< 1
Contamination Sensitivity	Yes	Yes	Yes	Yes					Yes	Yes

* From photoheliograph angular stabilization sensor, which may be from support vehicle.
** When operating.

†All instruments on at same time for quick recycling without warmup delay.

Table 3-17. 0.5-Meter X-Ray Telescope Experiment Interface, Support, and Performance Requirements (Continued)

EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	a. Image Stab. with Signals From Bore Sighted Optical Tel.	b. High Resolution X-Ray Imaging Low Res. Spect.	c. Proportional Counter Spectral Energy Dist.	d. 1 High Res. X-Ray Spectroscopy	e. (Additional Exp. Not Yet Defined)				ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	Sun synchronous	Sun synchronous	Sun synchronous	Sun synchronous	Sun synchronous					Sun synchronous
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0					55	55
Desired Altitude, km	500	500	500	500						500
(n.mi.)	(270)	(270)	(270)	(270)						(270)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740					370 to 740	370 to 740
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	200				(200 to 400)	(200 to 400)
Orientation:										
Observed Object Location	Stars/sun	Sun	Sun	Sun	Sun				Sun	Stars/sun
Observed Object Brightness, mag., m_v	-2.5 to sun	Sun	Sun	Sun	Sun				Sun	Stars/sun
Observation Field of View	2.91×10^{-3} rad (10 arcmin)	2.91×10^{-3} rad (10 arcmin)	2.91×10^{-3} rad (10 arcmin)	2.91×10^{-3} rad (10 arcmin)					2.91×10^{-3} rad (10 arcmin)	2.91×10^{-3} rad (10 arcmin)
Pointing Accuracy, rad										
(arcsec)										
Pointing Stability, rad/obs time	5×10^{-6}	5×10^{-6}	1.2×10^{-5}	5×10^{-6}					5×10^{-6} to 1.2×10^{-5}	5×10^{-6}
(arcsec/obs time)	(1)	(1)	(2.5)	(1)					(1 to 2.5)	(1)
Slew Rate, max., rad/sec	5×10^{-5}	$5 \times 10^{-}$		5×10^{-6}						5×10^{-5}
(arcsec/sec)	(10)									(10)
Slew Rate, min., rad/sec	5×10^{-7}	5×10^{-7}	5×10^{-7}	5×10^{-7}					2.5×10^{-6}	5×10^{-7}
(arcsec/sec)	(0.1)	(0.1)	(0.1)	(0.1)					(0.5)	(0.1)
Pointing Hold Time, sec	Up to 2700	Up to 2700	Up to 2700	Up to 2700					Up to 2700	Up to 2700
Data Requirements/Observation Cycle:										
Number of Data Sets/Orbit	1	10	10	10						
Imaging Data*										
Desired Resolution, (spatial or spectral)	5×10^{-6} rad (1 arcsec)	9.7×10^{-6} to 1.2×10^{-5} rad (2 to 5 arcsec)	-	10^{-11} m (0.1 Å)					9.7×10^{-6} to 1.2×10^{-5} rad (2 to 5 arcsec)	5×10^{-6} rad (1 arcsec) 10^{-11} m (0.1 Å)
Equiv. Image Format Size, mm	25.4 × 25.4	19 × 19	-	-					25.4 × 25.4	19 × 19
Picture Elements/Image	2.756×10^5	2.756×10^5	-	-					2.756×10^5	2.756×10^5
Images/Data Set	-	1	-	-					1	1
Images/Second	10 to 0.1	10 to 0.1	-	-					0.1, 1	10
Photometric Resolution, %, bits	1, 7	1, 7							1, 7	1, 7
Equiv. Analog Data, MHz	----	----								
Equiv. Digital Data, bits/image	1.93×10^6 to 1.93×10^7	1.93×10^6 to 1.93×10^7	-	-					(1.93×10^6)	(1.93×10^7)
Non-Imaging Data: Command Data, bps										
Science/Exp. Data, bps	200	200	(2000)	10,000					10,000	10,000
Housekeeping Data, bps	70	70	70	70					70	70
Special Requirements:										
Updating Cycle, Years	-	2	1	1					-	1 to 2
Mass, kg/yr (Weight, lb/yr)	-	27 (60)	22 (48)	27 (60)					-	76.5 (168)
Volume, m^3/yr (ft^3/yr)	-	0.085 (3)	0.056 (2)	0.085 (3)					-	0.23 (8)
Alternate Imaging Option:										
Film Width, mm	35	35	----	----						
Film per Orbit, cm (in)	3.5 (1.38)	35 (13.8	----	----						

*Imaging data parameters represent (hard wire) inputs to local processing, not output data transmission rate.

that the instrumentation section intercepts the plane of best focus. It is also necessary to boresight the guide telescope with the reference electronic imaging attached to the X-ray telescope optical axis.

3.4.3.5.2 Calibration. Sample images and electronic observations will be made and immediately analyzed. Standard-source radioactive elements (long half-life) are used continuously during actual operation, if desirable. The grazing-incidence spectrograph is particularly sensitive and will require unusual techniques for accurate calibration.

3.4.3.5.3 Observation. During normal operation the experiment will operate automatically and the crew will be required to monitor the experiment periodically. In the event of failure which prevents automatic operation, the crew will control the experiment manually until repairs can be made. In the manual mode, the crew will be involved continually during observation periods.

3.4.3.5.4 Scheduled Maintenance. The electrostatic shield, imaging tubes, detection circuits, and exposure sequencing receive periodic remote checks and more intensive examination based on performance time history during the maintenance period. Where sensitivities of imaging tubes or detectors are below acceptable range, they will be replaced. Alignment mechanism will be readjusted and calibrated to enable a maximum degree of remote control about optimum operating points. The grazing-incidence optics will be examined for deterioration, warping, or aging.

3.4.3.6 Available Background Data

a. Advanced Astronomy Missions Concept Study, NAS8-24000, Martin-Marietta Corporation, Denver Colorado.

b. Large Erectable Space Structures Study, NAS8-18118, Convair division of General Dynamics, San Diego, California.

c. Orbital Astronomy Support Facility, NAS8-21023, Douglas Missiles & Space Systems Division, Santa Monica, California.

3.4.4 SOLAR CORONAGRAPH EXPERIMENTS

3.4.4.1 Scientific or Technical Objectives. Continual observations of the solar corona from 1 to 30 solar radii are desired. Moving plasma cloud characteristics can be obtained better in space than from ground sites since the integrated white-light corona is much fainter than the Earth's integrated sky (atmospheric) background. The coronal monitoring is expected to detect outward-waving disturbances along coronal streams and to determine quantities of matter involved as well as phase velocities. Hopefully, the information obtained will give insight to the problem of coronal rotation.

3.4.4.2 Description. The experiment is conducted with a 1- to 6-solar radii coronograph and a 5- to 30-solar radii coronograph to enable better sensitivity to the coronal illumination which varies greatly with increase in distance from the sun.

The inner corona will be imaged at selected intervals to obtain information on coronal structures and relative velocities. The coronal phenomena will be correlated to solar-disk activity observed by the boresighted instrument group directed toward a selected-area (3.1×10^{-4} rad, 1.1 arcmin) field of view. To obtain best blocking of the solar disk by the coronagraph occulting disks, the coronagraph assembly is solar-disk centered. The image at the output of the coronagraph is recorded by an electronic imaging tube similar to that described in Table 3-6.

Concurrently with imaging of the inner corona by the 1- to 6-solar radii coronagraph, the 5- to 30-solar radii coronagraph will be utilized to image the outer corona at selected intervals. Recording is accomplished by an imaging tube similar to that described in Table 3-6.

3.4.4.3 Observation/Measurement Program. The 1-6 and 5-20 solar radii coronagraphs will operate continually on the sun side of the orbit. There will be an average of one exposure every three minutes while on the sun side (total of 16 exposures every orbit) for each of the two coronagraphs. Setup, operation, and maintenance time requirements are estimated in Table 3-18.

3.4.4.4 Experiment Interface, Support and Performance Requirements. The coronagraph assembly may be assigned to the same supporting vehicle as the other solar experiments; however, where the others are directed as a set to observe a particular spot on the sun, the coronagraph needs to be kept centered on the solar disk to enable blanking of the solar disk so that the corona may be observed. Table 3-19 shows requirements upon the supporting space vehicle.

3.4.4.5 Potential Role of Man. Setup and maintenance requirements are summarized for the coronagraph assembly in Table 3-18. Man's utilization in the operation of the instrument is for emergency backup modes only.

3.4.4.5.1 Deployment. The two coronagraphs will be mounted on a common support structure (optical bench) at launch. Covers and lens caps will be removed, and the sun sensor will be erected prior to release of the equipment for operation.

3.4.4.5.2 Alignment. The optics of each coronagraph is an independent sealed unit requiring no further adjustment. The positions of the external occulting disks are adjusted in orbit to obtain maximum suppression of diffraction effects. Adjustment of the internal occulting disk will be infrequent. Sample exposures obtained during calibration at 180 day intervals will be compared against remotely controlled performance checks and will serve as a record of alignment. The use of a common optical bench assures the boresight alignment of the two coronagraph optics systems to each other.

Table 3-18. Operation and Maintenance Time Estimates

Function	Astronomer/ Astrophysicist (hr/180 days)	Elec/Mech Eng (hr/180 days)	Photo/Optic Tech (hr/180 days)	Total Crew Time (hr/180 days)
Setup*				
Deployment		(1.0)		(1.0)
Alignment		(1.0)		(1.0)
Calibration		(1.0)		(1.0)
Operation**				
Monitor Exp.	60			60
Maintenance				
Scheduled Maintenance and Service		1.0	1.3	2.3
Unscheduled Maintenance		0.8		0.8

*Deployment, alignment and calibration tasks will be performed initially and following each corrective maintenance activity (average 0.2 time per 180 days).

**Assume 16 hours observation time per day (sun side of orbit).

3.4.4.5.3 Calibration. Intensity calibration wedges on the photographs are used. Depending on the frequency of photographs and the type of phenomenon being observed, it may be convenient to omit the wedges from many of the photographs during operation, and only take intensity-test images at intervals.

3.4.4.5.4 Operation. During normal operation the experiment will operate automatically and the crew will be required to monitor the experiment periodically. In the event of failure which prevents automatic operation, the crew will control the experiment manually until repairs can be made. In the manual mode the crew will be involved continually during observation periods.

3.4.4.5.5 Unscheduled Maintenance. Requirements arise only from unusual failures of electrical components, cameras, or supporting structures, or from damage to camera optics, as from sudden shock causing misalignment.

3.4.4.5.6 Scheduled Maintenance. Requirements are examination of the camera optics and mechanisms for deterioration.

Table 3-19. Coronagraph Assembly Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Inner Corona Imaging	b. Outer Corona Imaging							MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	One to six solar radii coronagraph	Five to 30 solar radii coronagraph								Simultaneous
Launch Mass, kg (Weight, lb)									955	955
Logistics Support										
Consumables, kg/180D (lb/180D)	32 (70) (if film used)	32 (70) (if film used)							64 (140) (if film used)	640 (1400)
Spares, kg/180D (lb/180D)	10 (22)	10 (22)							20 (44)	
Crew Support										
Initial Setup, Manhours/180D										
Periodic Serv. & Maint., Manhours/180D	2.7 hrs/180D	2.7 hrs/180D								5.4 hrs/180D
Operation, Remote Control, Manhours/Observation Cycle	0.30 hr/24 hr-da	0.30 hr/24 h4								
Electric Power:										
Peak Load, Watts	30	30							60	60
Average Load, Watts	30	30							60	60
Standby Load, Watts	15	20							35	35
Environmental Control										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	263 to 313	263 to 313							263 to 313	263 to 313
Temp. Range, Ops., °K	291 to 297	291 to 297							291 to 297	291 to 297
Max. Temp. Difference, °K	4	4								
Relative Humidity, %	≤ 50, pref. < 40								≤ 50	≤ 40
Atmosphere Limit, N/m² (psi)	0 to 10^5 (0 to 15) 1.33 × 10^{-4} (10^{-7} torr)	0 to 10^5 (0 to 15) 1.33 × 10^{-4} (10^{-7} torr)							0 to 10^5 (0 to 15)	1.33 × 10^{-4} (10^{-7} torr)
Cleanliness Class	100,000 pref. vac.	100,000 pref. vac.							100,000	100,000
Gravity Level, Max. g	< 10^{-3}, to avoid flexure	< 10^{-3}, to avoid flexure							-	10^{-3} to avoid flexure
Radiation Sensitivity, millirad/hr										
Contamination Sensitivity	Slight if film used	Slight if film used							Slight	Slight

Table 3-19. Coronagraph Assembly Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS \ EXPERIMENT	a. Inner Corona Imaging	b. Outer Corona Imaging						MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:									
Desired Inclination, deg	sun synchronous	sun synchronous						sun synchronous	sun synchronous
Acceptable Inclination, deg	55° to 0°	≥ 55° to 0°						55° to 0°	-
Desired Altitude, km	500	500							500
(n.mi.)	(270)	(270)							(270)
Acceptable Altitude, km	370 to 740	370 to 740						370 to 740	
(n.mi.)	(>200 to 400)	(>200 to 400)						(>200 to 400)	
Orientation:									
Observed Object Location	Solar corona	Solar corona						-	-
Observed Object Brightness, mag., m_v	Sun	Sun						Sun	Sun
Observation Field of View, rad	0.057	0.26							0.057
(deg.)	(3.25)	(15)							
Pointing Accuracy, rad	7.3×10^{-5}	7.3×10^{-5}						7.3×10^{-5}	7.3×10^{-5}
(arcsec)	(15)	(15)						(15)	(15)
Pointing Stability, rad/obs time	5×10^{-6}	2.4×10^{-5}						2.4×10^{-5}	5×10^{-6}
(arcsec/obs time)	(1) avoid flexure	(5) avoid flexure						(5)	(1) avoid flexure
Slew Rate, max., rad/sec	2.4×10^{-4}	2.4×10^{-4}							2.4×10^{-4}
(arcsec/sec)	(60)	(60)							(60)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}							5×10^{-6}
(arcsec/sec)	(1)	(1)							(1)
Pointing Hold Time, sec	≤ 2700	≤ 2700							≤ 2700
Data Requirements/Observation Cycle:									
Number of Data Sets/Orbit	10	10						10	100
Imaging Data									
Desired Resolution,	5×10^{-5} rad	14.5×10^{-5} rad							5×10^{-5} rad
(spatial or spectral)	(10 arcsec)	(30 arcsec)							(10 arcsec)
Equiv. Image Format Size, mm	17.9 x 17.9	24 x 24							
Picture Elements/Image	1.369×10^{6}	3.24×10^{6}							$4.609 \times 10^{+6}$ (2 images)
Images/Data Set	4	4							
Images/Second	5.5×10^{-3} to 1	5.5×10^{-3} to 1						5.5×10^{-3} to 1 (2 images)	5.5×10^{-3} to 1 (2 images)
Photometric Resolution, %, bits	7	7						7	7
Equiv. Analog Data, MHz	0.48	1.13						1.61	1.61
Equiv. Digital Data, bits/image	9.583×10^{6}	2.268×10^{7}						3.226×10^{7} (if digital)	3.226×10^{7} (if digital)
Non-Imaging Data: Command Data, bps									
Science/Exp. Data, bps	100	100						200	200
Housekeeping Data, bps	10	10						20	20
Special Requirements:									
Updating Cycle, Years	1	1							1
Mass, kg/yr (Weight, lb/yr)	34.5 (76)	34.5 (76)							60 (132)
Volume, m^3/yr (ft^3/yr)	0.085 (3)	0.085 (3)							0.17 (6)
Alternate Imaging Option									
Film Width, mm	35	35							
Film/Orbit, cm (in)	140 (55)	140 (55)							

3.4.4.6 Available Background Data

a. H. Zirin, Photoheliograph Study for the Apollo Telescope Mount (Briefing, Charts and Descriptions), JPL, Pasadena, Calif, 15 November 1967.

b. Experiment Implementation Plan for Apollo Telescope Mount, Exp. 5055 UV Spectrometers, NASA Marshall Space Flight Center, 3 April 1967.

c. "Orbital Astronomy Support Facility (OASF) Study", Vol III, Task B, Instruments for Orbital Astronomy, 28 June 1968, DAC 58143.

3.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

Table 3-20 shows the combined impact of the solar astronomy experiments operating as nearly simultaneously as the experiment facility items set forth in this document allow. Data is obtained electronically to avoid constant recycling of film on station. The data load is expected to be transferred by many parallel hard-wire channels to the supporting vehicle (RAM, etc.) and would be absorbed by a rapid-access memory for immediate information processing or later transfer to the information processing point. Nominally a continual raw data rate of about 9.3×10^8 to 3.9×10^9 bits per set of data is expected at intervals varying from once per three minutes to once per second. Variation of information flow (images or data sets versus time) enables reducing data rate but results in decreased information output. Sampling at 10-sec intervals and near real-time information bulk processing (equivalent compression 50 to 100) will reduce output data rate tremendously (probably to less than 10 Mbs). It is expected that each telescope and instrument assembly will have a liquid jacket for minimizing temperature differences and maintaining the optics within tolerable temperature limits. Each telescope or instrument will be removable from this equivalent cold-plate frame or shell.

3.6 POTENTIAL MODE OF OPERATION

For best observation and least interaction from other experiments, the solar astronomy experiments would probably be accomplished from a free-flying platform or an experiment module rather than attached to a large Space Station.

The 1.5-m photoheliograph, the 0.25-m XUV spectrophotometer, and the X-ray telescopes ideally would be operated simultaneously to obtain correlatable data across the total spectral region from 10^{-6}m (10,000 Å) to about 2×10^{-10}m (2 Å). Not only would data from the various instruments of the three telescopes be obtained at the same time, but the three telescopes would point at the same spot on the sun. Typically, image exposure and data sampling durations initially would be kept small (about 1/10 second or less) and pairs of data sets separated by a precise time interval would enable lateral velocity measurements of the observed granular structure as well as rate-of-change estimates of other solar phenomena.

Table 3-20. FPE Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	3.4.1 Photoheliograph Observations/ Measurements	3.4.2 0.25 M XUV Spectroheliograph Observations Measurements	3.4.3 0.5 M X-Ray Telescope Exp Experiment	3.4.4 Solar Coronagraph Observations/ Measurements					ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:										
Launch Mass, kg (Weight, lb)	2080 (4590)	431 (950)	400 (880)	434 (955)						3345 (7375)
Logistics Support										
Consumables, kg/180D (lb/180D)	454 (1000)	92 (203)	15 (33)	64 (140)					625 (1376)	6250 (13760)
Spares, kg/180D (lb/180D + Updating*)	75 (165)	40 (88)	45 (99)	20 (49)					180 (396)	---- ----
Crew Support										
Initial Setup, Manhours/180D	4	0.5	1	3						8.5
Periodic Serv. & Maint., Manhours/180D	13.5	3.5	6	5.4						18.4
Operation, Remote Control, Manhours/Observation Cycle	0.3 to 0.75	0.05	0.55	0.3						0.3 to 0.75 (20–45 min)
Electric Power:										
Peak Load, Watts	245	70	595	60						970
Average Load, Watts	215	55	450	60						780
Standby Load, Watts	175	70	260	35						540
Environmental Control										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	263 to 297	263 to 297	263 to 297	263 to 297						263 to 297
Temp. Range, Ops., °K	291 to 297	290 to 294	290 to 294	291 to 294						290 to 296
Max. Temp. Difference, °K	<2	<2	<2	<2						<2
Relative Humidity, %	~0, operating	<10	~0	< 10, ~0						Small
Atmosphere Limit, N/m^2 (psi)	1.33×10^{-5} (10^{-7} torr, ops)	1.33×10^{-5} (10^{-7} torr)	1.33×10^{-5} (10^{-7} torr)	1.33×10^{-5} (10^{-7} torr)						1.33×10^{-4} (10^{-7} torr)
Cleanliness Class	10,000	10,000	10,000	100,000					1000,000	10,000
Gravity Level, Max. g	10^{-4}	10^{-4}	10^{-4}	10^{-3}						10^{-4}
Radiation Sensitivity, millirad/hr	1	1	1	—						1
Contamination Sensitivity	Yes	Yes	Yes	—						Yes

*See special requirements

Table 3-20. FPE Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	3.4.1 Photoheliograph Observations/ Measurements	3.4.2 0.25 M XUV Spectroheliograph Observations Measurements	3.4.3 0.5 M X-Ray Telescope Exp Experiment	3.4.4 Solar Coronagraph Observations/ Measurements				ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:									
Desired Inclination, deg	Sun synchronous	Sun synchronous	Sun synchronous	Sun synchronous				—	Sun synchronous
Acceptable Inclination, deg	≥ 55 to 0	≥ 55 to 0	≥ 55 to 0	55 to 0				≥ 55 to 0	—
Desired Altitude, km	500								500
(n.mi.)	(270)	(270)	(270)	(270)					(270)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740				370 to 740	
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)				(200 to 400)	
Orientation:									
Observed Object Location	Sun	Sun	Sun	Sun					Sun
Observed Object Brightness, mag., m_v	Sun	Sun	Sun	Sun					Sun
Observation Field of View	3.2×10^{-4} (1.1 arcmin)	9.6×10^{-3} rad (32 arcmin)	2.9×10^{-3} rad (10 arcmin)	5×10^{-2}, 0.26 rad (3.25°, 15°)				3.2×10^{-4} to 0.26 rad (1.1 arcmin to 15°)	Varies
Pointing Accuracy, rad	5×10^{-6}	1.2×10^{-5}	5×10^{-6}	7.5×10^{-5}				5×10^{-6} to 7.5×10^{-5}	5×10^{-6}
(arcsec)	(1)	(2.5)	(1)	(15)				(1 to 15)	(1)
Pointing Stability, rad/obs time	5×10^{-8}	5×10^{-7}	2.4×10^{-6}	5×10^{-6}				5×10^{-7}	5×10^{-8}
(arcsec/obs time)	(0.017)	(0.1)	(0.5)	(1)				(0.1)	(0.01)
Slew Rate, max., rad/sec	5×10^{-5}	5×10^{-5}	5×10^{-5}	2.9×10^{-4}				5×10^{-5}	2.9×10^{-4}
(arcsec/sec)	(10) max	(10) max	(10)	(60)				(10)	(60) max
Slew Rate, min., rad/sec	5×10^{-7}	5×10^{-7}	5×10^{-7}	5×10^{-6}				5×10^{-7}	5×10^{-7}
(arcsec/sec)	(0.1)	(0.1)	(0.1)	(1)				(0.1)	(0.1)
Pointing Hold Time, sec	2700	19.8 to 2700	Up to 2700	2700				Up to 2700	Up to 2700
Data Requirements/Observation Cycle:									
Number of data sets/orbit	1 to 10	1 to 10	1 to 10	10 to 100					
Imaging Data**									
Desired Resolution (spatial or spectral)	5×10^{-7} rad (0.1 arcsec) 2×10^{-13} m (0.002 Å)	5×10^{-6} rad (1 arcsec)	9.7×10^{-6} to 1.2×10^{-6} rad 2 to 5 arcsec 10^{-11} m (0.1 Å)	5×10^{-5} to 14×10^{-5} rad (10 to 30 arcsec)					
Equiv. Image Format Size, mm	25.4 × 25.4 100 × 100							25.4 × 25.4	100 × 100
Picture Elements/Combined Data Sets	1.14×10^7	2.824×10^7	2.756×10^5	4.609×10^6					1.17×10^9
Images/Data Set	80 to 90	1	1	2				84	94
Images/Second	0.1 to 1	0.1 to 1	1, 10	5.5×10^{-3} to 1				Varies (5.5×10^{-3} to 10)	Up to 94/sec
Photometric Resolution, %, bits	1, 7	1, 7	1, 7	1, 7					1, 7
Equiv. Analog Data, MHz	4.2 H-α, WL, XUV	2.9		1.61 Optional				Variable, depending upon extent of simultaneity achieved	8.71
Equiv. Digital Data, bits/data set	7×10^8 to 4×10^9	1.97×10^8	1.93×10^7	1.185×10^7 Optional					0.93×10^9 to 4.2×10^9 per comb. data set
Non-Imaging Data: Command Data, bps									
Science/Exp. Data, bps	2100		10,000	200					12,300
Housekeeping Data, bps	5300	45	70	20					5,430
Special Requirements:									
Updating Cycle, Years	2	1	2	1				2	1 to 2
Mass, kg/yr (Weight, lb/yr)	100 (220)	36 (80)	76 (168)	60 (132)					272 (600)
Volume, m^3/yr (ft^3/yr)	0.03 (11)	0.011 (4)	0.023 (8)	0.017 (6)					0.82 (29)

* Dependent on degree of interconnection and cooperative operation with supporting vehicle's experiment information processing computers.

**Imaging data indicated is input to local processing, not output data transmission rate.

The supporting vehicle would supply offset star tracking and solar observation location services enabling pointing of the correlated solar telescopes to any selected location on the sun within 4.85×10^{-6} rad arcsec.

The coronagraph assembly may be assigned to the same supporting vehicle but will need limited gimballing (or flexure mounting) to enable the coronagraphs to be centered on the solar disk so that light from the solar disk may be blocked to enable corona phenomena to be observed and measured. If assignment of the coronagraph assembly to a free-flying supporting vehicle causes adverse interactions or undue access problems, the assembly may be assigned to the Space Station or another supporting vehicle. However, time and spatial correlation of phenomena in the corona and activity on the solar surface is necessary and probably easier if the solar-surface-area-pointed assembly of telescopes and the solar-disk-centered coronagraph assembly are located on the same supporting vehicle.

Simultaneous sampling of solar phenomena by all the instruments at precisely timed intervals may be difficult to achieve in initial configurations until onboard data storage and processing techniques are sufficiently developed. Possibly a series of evolutionary steps may be necessary during the 1976 to 1986 period to enable more of the related data sets to be acquired and correlated more continually.

Initially, capability will develop in the lower-inclination orbits to handle precise solar observations and measurements during the available observation time. Orbit dark-side environment, although useful for optical alignment and calibration on very bright reference stars, tends to be quite different from the orbit light-side environment. Phenomena occurring on the sun during the time the supporting vehicle is on the dark side of the orbit would be missed in lower-inclination orbits. Hence, after capability for more continual observations is developed in a more accessible orbit inclination such as 55°, a solar astronomy vehicle periodically visited by man could be launched into a sun-synchronous orbit about 5 years later with capability for simultaneous continual observations.

The application of this experiment package to each of the proposed mission modes is as follows:

Mission A - Limited On-Orbit Stay Time With Space Shuttle. This mission has limited potential due to the short on-orbit stay time and the need for many, many hours of observation. This mission mode might, however, be used to check-out the experiments to be flown eventually in a Mission B or C mode.

Mission B - Extended Orbit Stay Time Revisited by Shuttle. This mission is attractive for the Advanced Solar FPE. The possibility of a sun-synchronous orbit is more likely in this mode than any other, and this would certainly increase the observing time. Either film or electronic imaging could be used in this mode, but the film option would require frequent logistics flights.

Without film, the nominal revisit interval would be about one year. Maintenance, repair, and sensor updating could be accomplished during these revisits.

Mission C - Extended Mission In Conjunction With Space Station. This mode would be best for the film option by allowing frequent exchange, but it would eliminate the possibility of a sun-synchronous orbit. Either mode B or C is acceptable from a scientific viewpoint with C adding some desired but not essential capability.

3.7 ROLE OF MAN

Man is expected to cause evolutionary improvement of solar astronomy technology, equipment, and observation/measurements by continual monitoring of experiment operations and evaluation of results, including analysis of error sources. Man is expected to be in experiment operations such as preparation of the solar astronomy equipment, periodic-servicing maintenance, and periodic remote monitoring and control of operations. Man will periodically visit the solar astronomy facility equipment in space for servicing and maintenance. Supporting the astronomy facility from the ground, man is of course necessary to the quick analysis and interpretation of data which enables updating of equipment and procedures and development of the desired simultaneous continual observation/measurement capability. Much of man's activity in space in support of the solar astronomy equipment will consist of installation of new equipment, or maintenance after critical failures, and more intensive calibration and alignment than can be accomplished by remote control.

3.8 SCHEDULES

Predicted schedules for concept definition, design, manufacturing, test, and operations of the Solar Astronomy Facility equipment is shown in Table 3-21.

3.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

Special facilities and operational support requirements during the prelaunch period are set forth in Table 3-22, together with requirements imposed on launch vehicles (Shuttle) and Space Stations.

3.10 SAFETY ANALYSIS

Evaluation of the FPE for safety implications and hazards indicates some hazard in the form of high voltages for imaging tubes (which can be insulated), and the use of some materials in these tubes which may be poisonous if accidentally broken during servicing.

Table 3-21. Estimated Schedule for Advanced Solar Astronomy

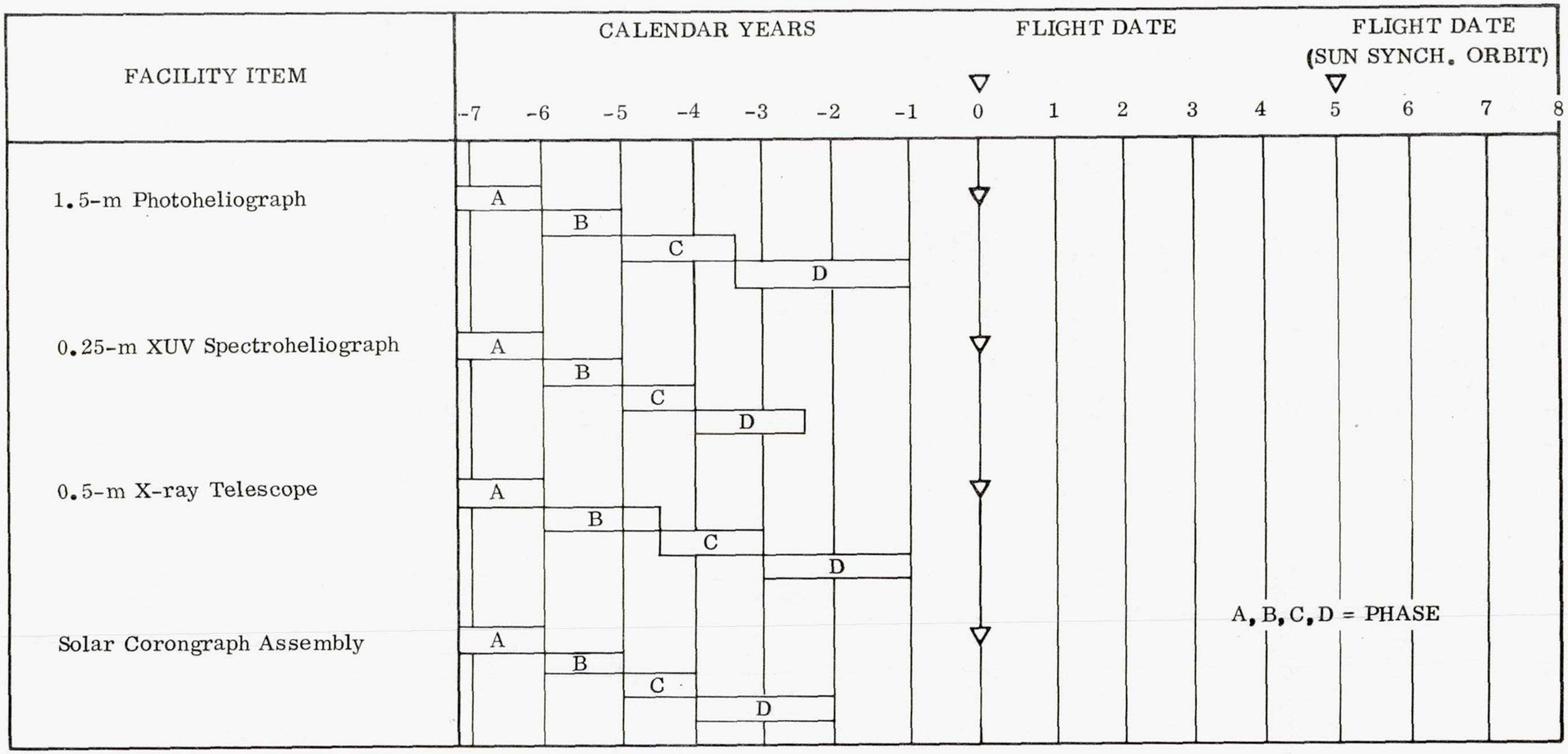


Table 3-22. Prelaunch Support Requirements and GSE

Facilities
Optical Support Laboratory with at least 100,000-class cleanliness (10,000-class preferred) with room having stellar and solar viewing access.
Transportation and Handling
Shipping and Storage Containers
Lifting Adapters
Film Transportation System
Test and Checkout
1 Instrumentation Tape Recorder
1 Video Tape Recorder
4 Digital Tape Recorders
1 Monitoring and Control Console for Advanced Solar Astronomy (duplicate of ground station unit)
1 Digital Image Processing Equipment
4 Optical and Electronic Test Sets

3.11 AVAILABLE BACKGROUND DATA

a. NASA Document SP-213, A Long Range Program in Space Astronomy, Position Paper of the Astronomy Missions Board, July 1969.

b. Astronomy Review Group Meetings, MSFC, Summer and Fall, 1970.

c. Astronomy Mission Board Meetings, Summer, 1970.

d. Orbital Astronomy Support Facility (OASF) Study, DAC 58143, 28 June 1968.

e. Experiment Module Concepts Study Interim Progress Report, Report XM TN-160, May 1970.

SECTION 4

INTERMEDIATE SIZE UV TELESCOPES

4.1 GOALS AND OBJECTIVES

Principal scientific goals of the ultraviolet experiments or observations with the intermediate UV telescopes are:

a. Spectrally selective ultraviolet imaging of galactic emission and reflection nebulae. These images will yield information about the interplay of excitation with the morphological relationships of nebulae, provide improved data on the interstellar gas-to-dust ratio, and give better insight concerning the nature and distribution of dust particles.

b. Spectrally selective ultraviolet imaging and photography of star clusters. Ultraviolet photometry of cluster stars will permit more accurate derivations of stellar evolutionary sequences, particularly for massive stars requiring large bolometric corrections. The clusters, being collections of stars with common chemical and physical origin, allow more definitive analyses of their emergent fluxes in terms of chemical composition and structural evolution. Their interaction with the surrounding interstellar medium, and the scattering and extinction properties of the medium itself, are important to observe in the ultraviolet where most of the flux from the young massive star lies.

c. Direct ultraviolet imaging and photography of galaxies. Images of nearby galaxies will improve the delineation of spiral structure due to increased contrast between star groups and dust lanes at shorter wavelengths. They will provide direct observations of the ultraviolet luminosity function, which is a necessary parameter in interpretation of ground observations of distant highly red-shifted galaxies. Photographs of more distant red-shifted galaxies will be extremely interesting to inspect for leakage of hydrogen Lyman-alpha radiation and its spatial distribution with respect to other structural features of these galaxies.

d. Slitless spectrography in the ultraviolet of selected large planetary nebulae. This technique will provide the means of obtaining monochromatic ultraviolet spatial images of essentially dust-free pure emission gas systems. These can be used for testing theories of excitation and emission of very low density plasmas, and for improving our understanding of the chemical composition of these nebulae.

e. Slit spectrography of specific features in large emission nebulae. These observations will be used to study collisional, radiative, and nonthermal excitation

processes in the nebulae. Identification of resonant lines from important species such as C, N, and O, which can be studied only in the ultraviolet, will allow determination of their abundances in the interstellar medium. The use of a slit spectrograph will permit a search for broadened nebular Lyman-alpha emission. Its detection would be significant in evaluating the efficiency of competing processes such as resonance scattering, two-photon emission, and grain emission.

f. Spectrographic and photographic observations of the brighter quasars and novae. The quasar spectra will allow the discovery of higher members of the Lyman series of hydrogen and of the red-shifted 5.84×10^{-8}m (584Å) helium and 3.04×10^{-8}m (304Å) ionized-helium resonance lines. Direct ultraviolet photographs of these objects would be of value in determining their far-ultraviolet colors and dimensions.

g. Concurrently with these specific observations and measurements, observations will be continued with a wide-field all-reflective telescope to accomplish the following:

1. Conduct an ultraviolet survey of the sky.

2. Obtain spectra in the ultraviolet region from selected strong ultraviolet sources and from the entire celestial sphere.

3. Provide survey data of selected areas for detailed investigation by the larger instrument.

4. Develop an ultraviolet technology base and determine man's potential in support of space astronomy.

4.2 PHYSICAL DESCRIPTION

The ultraviolet stellar survey facility items consist of a narrow-field 0.94-meter (37-inch) Ritchey-Chretien Cassagrainian type of telescope and a 0.3-meter wide-field UV telescope. Table 4-1 summarizes facility items and special experiment equipment versus predicted experiments or observation tasks. Specific instrument packages will be discussed under Experiment Program in Section 4.4. The facility items are discussed in Sections 4.2.1 and 4.2.2.

4.2.1 NARROW-FIELD UV TELESCOPE. The narrow-field UV telescope and its associated experiments form an ultraviolet energy gathering and processing system. The system is capable of accepting ultraviolet radiation from stars or nebulae and performing direct-field photography or spectrography. The pictures may be taken by either electronic or photographic processes and transmitted to the ground by

Table 4-1. Summary of Facility and Special Equipment Versus Experiments

	Facility Items				Special Experiment Equipment										
Experiment Class	0.94-Meter UV Narrow Field Telescope	0.3-Meter Widefield UV Telescope			Guide Star Trackers (2)	Field TV Relay/ Perform-ance Monitor	Combined Electronic/ Backup Film Camera	High Dispersion Spectrom-eter	Low Dispersion Spectro-graph	Objective Grating	Broad Band Filters	Wide-Field UV Electronic Camera Assembly	Backup Film Holder and Film Magazine Assembly	Optional Star Tracker/ Inertial Reference Assembly	Pattern Recogni-tion Star Field Lockon Unit
4.4.1 NARROW-FIELD UV TELESCOPE EXPERIMENTS															
a. Focus and Alignment	•				•	•	•	•	•	-	-	-	-	-	-
b. Guide Star Acquisition	•				•	•	-	-	-	-	-	-	-	•	-
c. Stellar Object Acquisition and Location	•				•	•	-	-	-	-	-	-	-	•	-
d. Electronic Imaging	•				•	•	•	-	-	-	-	-	-	•	-
e. Backup Film Imaging	•				•	•	•	-	-	•	-	-	-	•	-
f. Low Dispersion Spectroscopy	•				•	•	-	-	•	-	-	-	-	•	-
g. High Dispersion Spectroscopy	•				•	•	-	•	-	-	-	-	-	•	-
4.4.2 WIDE-FIELD UV TELESCOPE SURVEY EXPERIMENTS															
a. Focus and Alignment	-	•								•	•	•	•	•	•
b. Observation Area Acquisition and Location	-	•								•	•	•	-	•	•
c. Electronic Imaging	-	•								•	•	•	-	•	•
d. Backup Film Imaging	-	•								•	•	-	•	•	•
e. Objective Grating Spectrometry	-	•								•	•	•	•	•	•

Shuttle or communication relay link. The narrow-field telescope makes use of the following three instrument assemblies:

a. Composite-field camera, including photographic film transport, TV detectors, ultraviolet image converters, and filters for spectrally selective direct-field photography of nebulae, galaxies, and star clusters.

b. A high-dispersion spectrograph with moderate spectral resolution, for slitless spectrography and monochromatic photography of planetary nebulae and selected portions of diffuse nebulae.

c. Low-dispersion slit spectrography with low spectral resolution, for spectrography of fainter diffuse nebulae, galaxies, and quasars.

Figure 4-1 shows the telescope configuration in a typical deployed position, and Figure 4-2 shows the telescope in a stowed configuration for shirt-sleeve maintenance. Figure 4-3 shows a longitudinal cross-section of the telescope and its instruments. Telescope and associated instrument parameters are tabulated in Table 4-2. Weights, volumes, and envelope dimensions are given in Table 4-3. The functional relationship of the telescope and its instrument assemblies is outlined in Figure 4-4.

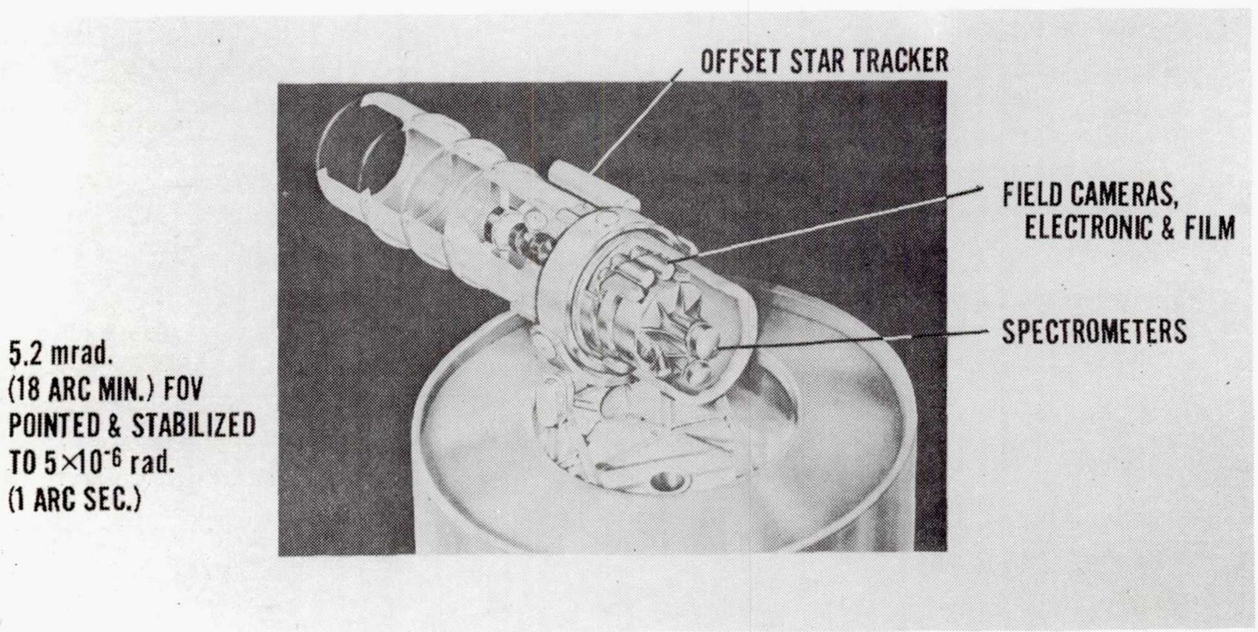


Figure 4-1. Telescope Deployed

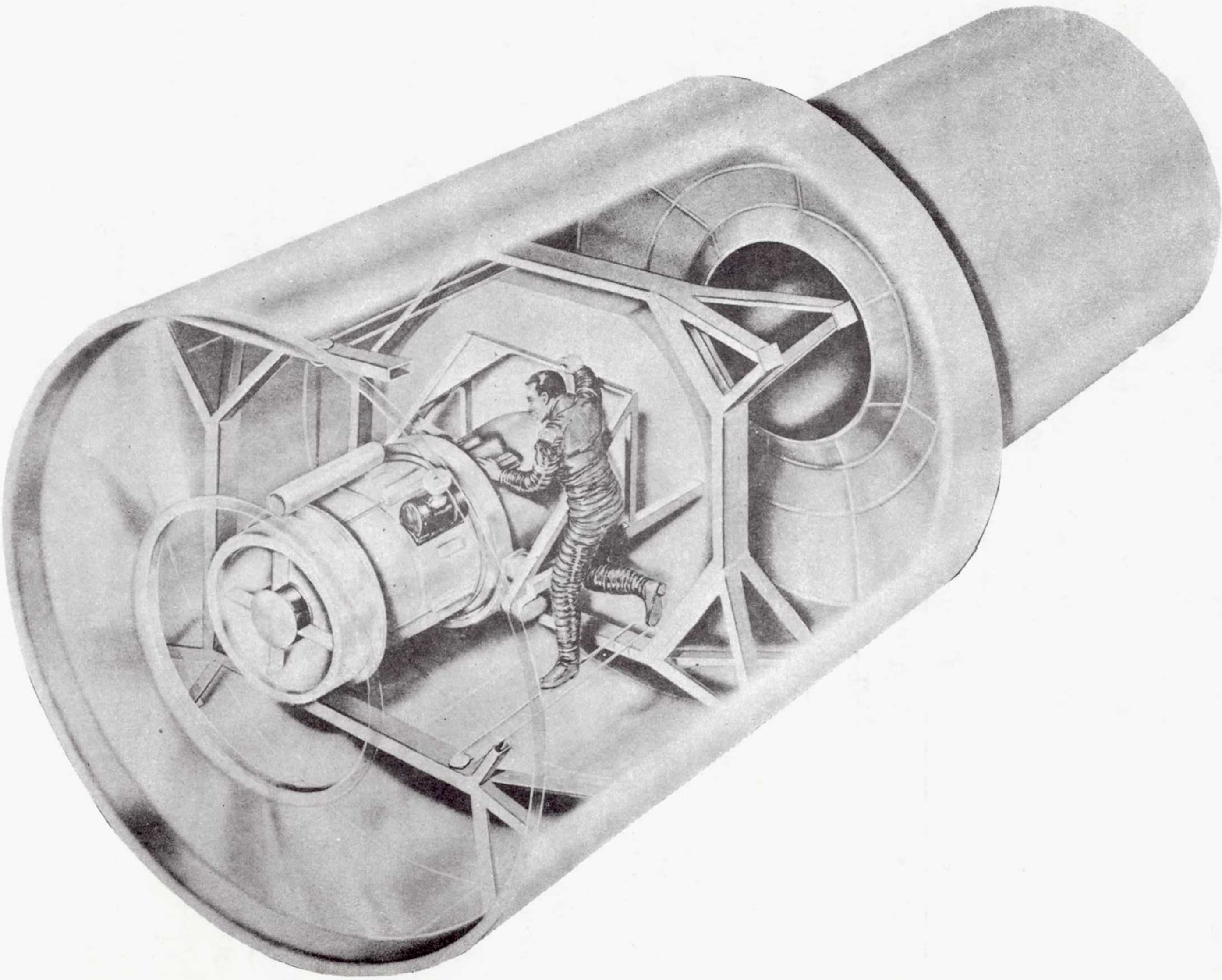
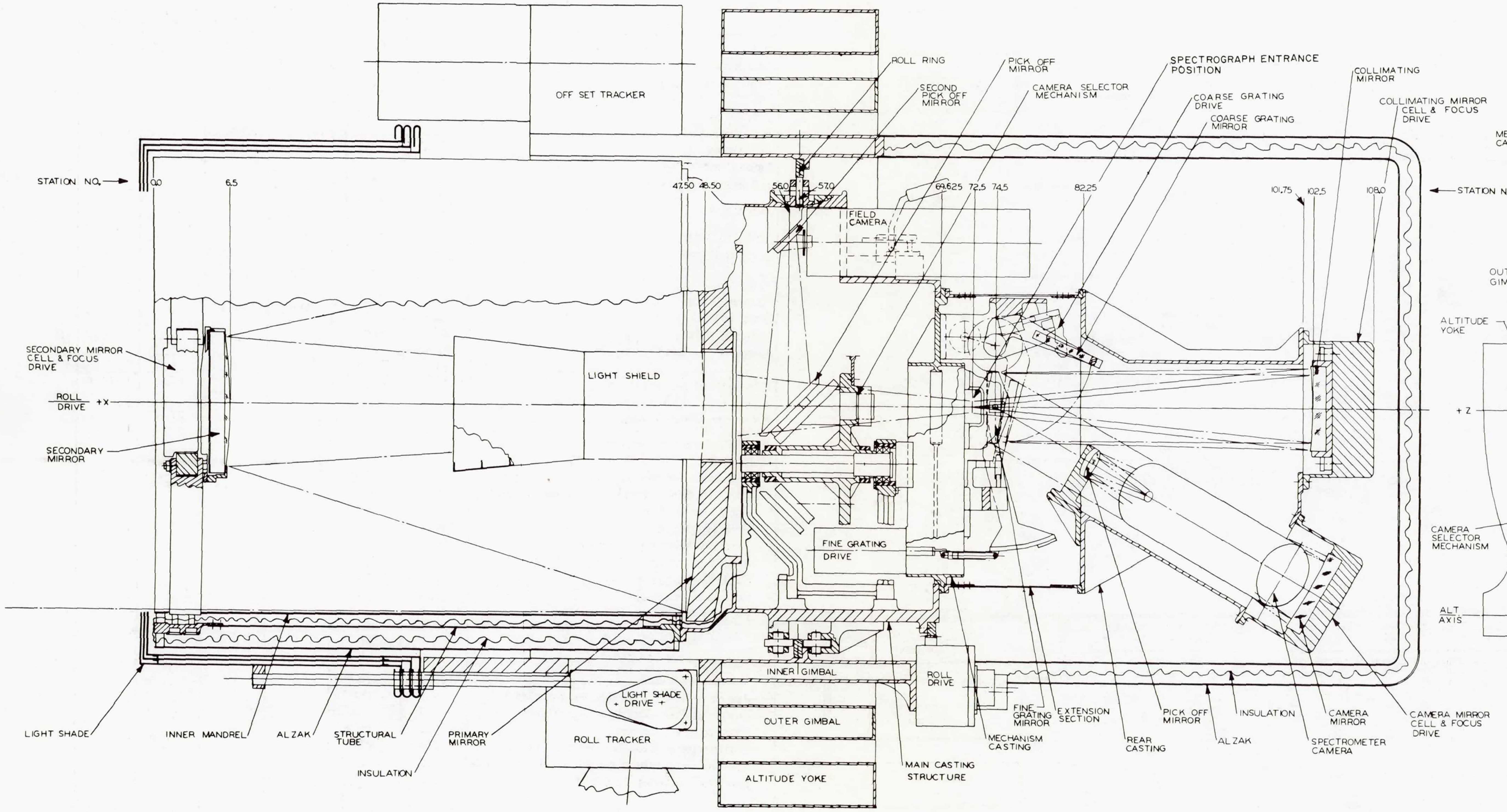


Figure 4-2. Telescope Stowed

Table 4-2. Narrow-Field UV Telescope and Associated Instrument Parameters

INSTRUMENT OR SUBSYSTEM	DESCRIPTION
Telescope	Ritchey - Chrétien Cassegrain Free Aperture 0.94 m (37 in) dia. Focal Ratio F/5.25: Effective Focal Length = 4.94 m (194 in) Plate Scale 2.02×10^{-3} rad (42 arcsec/mm) Reciprocal Plate Scale 4.95 μm/10^{-6} rad (24 μm/arcsec) Angular Resolution 2.9×10^{-6} rad (0.6 sec) at 219×10^{-3} rad (10 min) Half Field Angle
Field Cameras	Field Diameter 25.4 mm (1 inch); 4.6×10^{-3} rad (17.8 arcmin) Film or TV with or without image converter/intensifier Total Band Pass: UV 0.1 to 0.35 μm; IR 0.75-40 μm 4 position selector for band pass filters
Field TV Relay (Performance Monitor)	Acquisition Verification & Performance Checks TV Display at Control Console
Spectrograph High Dispersion	Stigmatic Configuration 1000 lines/mm Aspherized Plane Grating 762 mm (30 in) F.L. Collimator and Camera Dispersion: 1.3×10^{-3} μm/mm = 3.13×10^{-5} μm/arcsec = 1.9×10^{-3} μm/arcmin 3×10^{-8} m Bandwidth per Grating Position Total Bandwidth: 9×10^{-8} m to 4×10^{-7} m (900 Å to 4000 Å)
Spectrograph Low Dispersion	Stigmatic Configuration, 100 lines/mm Plane Grating Dispersion: 1.3×10^{-2} μm/mm = 3.1×10^{-4} μm/arcsec = 1.9×10^{-2} μm/arcmin
Guidance	Point anywhere in a Hemisphere Offset Star Tracker 0.022 rad (±1.25°) offset 5×10^{-6} rad (1 arcsec) on 7 Mag Star Tracking Capability



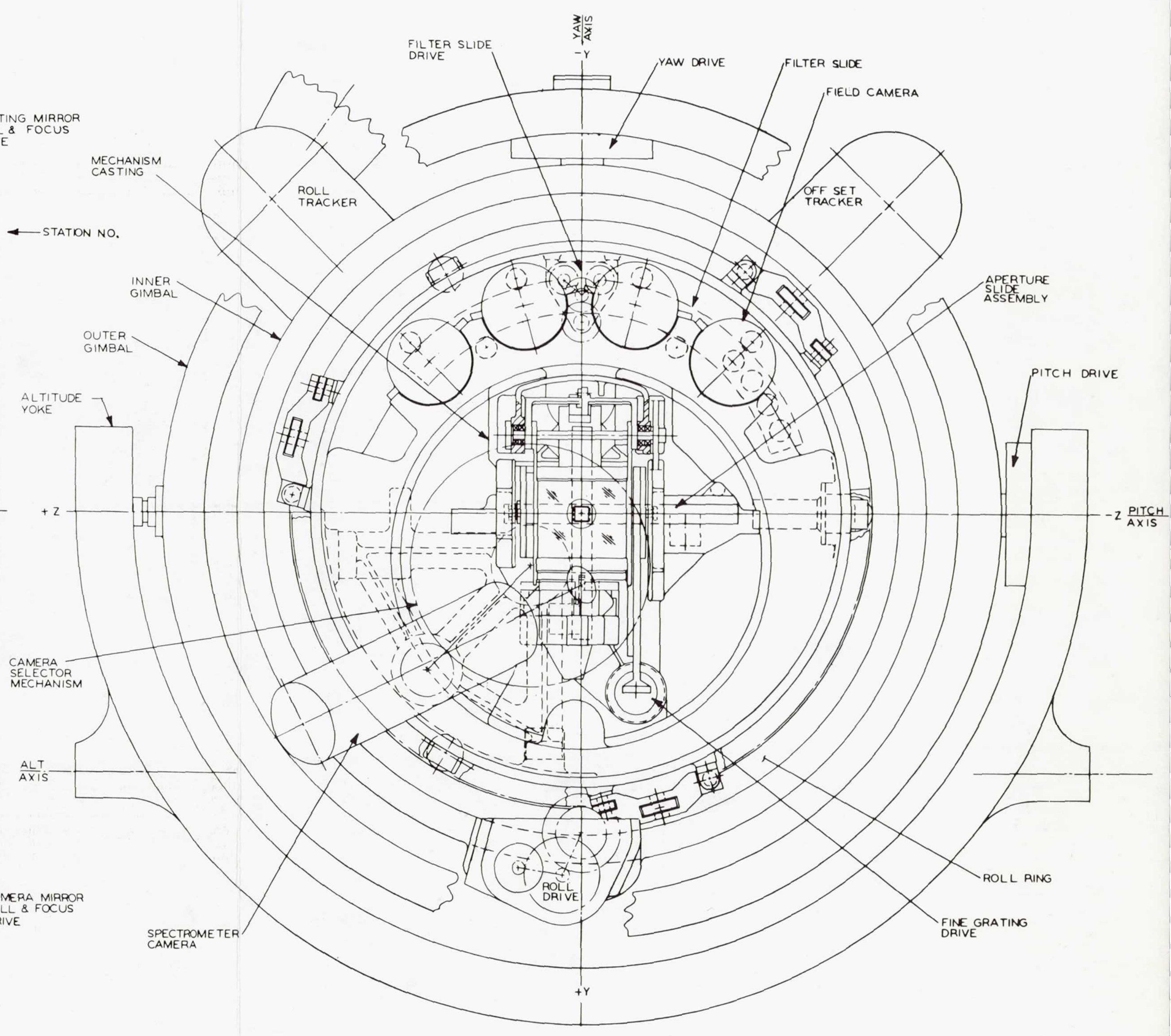


Figure 4-3. Narrow-Field UV Telescope Facility

Table 4-3. Narrow Field UV Telescope, Weights, Volumes, and Dimensions

Configuration Summary						
	Mass (Weight)				Volume	
Item	kg	(lb)	kg	(lb)	m^3	(ft^3)
Telescope and Instrument Package	515	(1134)	515	(1134)	7.08	(250)
Roll Ring	15.9	(35)				
Hood for Roll Ring	20.2	(45)				
OFG	18.2	(40)				
Rate Gyros	5.4	(12)				
Roll Tracker	10.0	(22)	163	(359)		
Roll Drive	13.6	(30)				
Inner Gimbal	41.0	(90)				
Sun Shade and Drive	34.1	(75)				
Yaw Drive	4.54 4.54	(10) (10)				
Outer Gimbal	51.0	(112)	60	(132)		
Pitch Drive	4.54 4.54	(10) (10)				
Yoke Arm	81.0	(178)	85.5	(188)		
Azimuth Table	48.5	(107)	66.6	(147)		
Altitude Drive	18.2	(40)				
Azimuth Drive	27.3	(60)	208	(460)	1.13	(40)
Elevator Platform	182.0	(400)				
	1100	(2420)			8.2	(290)
Pressurized Service Housing	2040	(4500)			37.4	(1356)
3.66m D ×3.66 m L (12 ft D×12 ft L)						
Estimated Gross Weight	3140	(6920)			37.4	(1356)
Field Camera & Telescope						
Secondary, Focus Drive & Vanes	26.3	(56)				
Telescope Structural Tube	38.8	(86)				
Inner Mandrel, Sheath & Telescope Insulation	17.2	(38)				
Light Shield (Inner)	2.25	(5)				
Primary Mirror	90	(200)				
Primary Mounting Hardware	11.3	(25)				
Main Casting and Primary Cell	94.8	(210)				
Cable Disconnects	9.1	(20)				
Roll Axis Bearings	5.05	(12)				
Camera Selector & Filters	31.8	(70)				
4 Cameras (Field)	54.5	(120)				
	382	(842)				
Spectrograph						
Mechanism Casting	22.7	(50)				
Aperture Slides & Calibrated Sources	9.1	(20)				
Coarse & Fine Gratings Plus Drives	20.8	(46)				
Camera Spectrograph	13.6	(30)				
Collimating & Camera Mirrors Plus Drives	34.6	(76)				
Spectrometer Structural Tube & Rear Frame	27.2	(60)				
Insulation & Outer Sheath	4.54	(10)				
	132.5	(292)				
	515	(1134)			7.08	(~250)

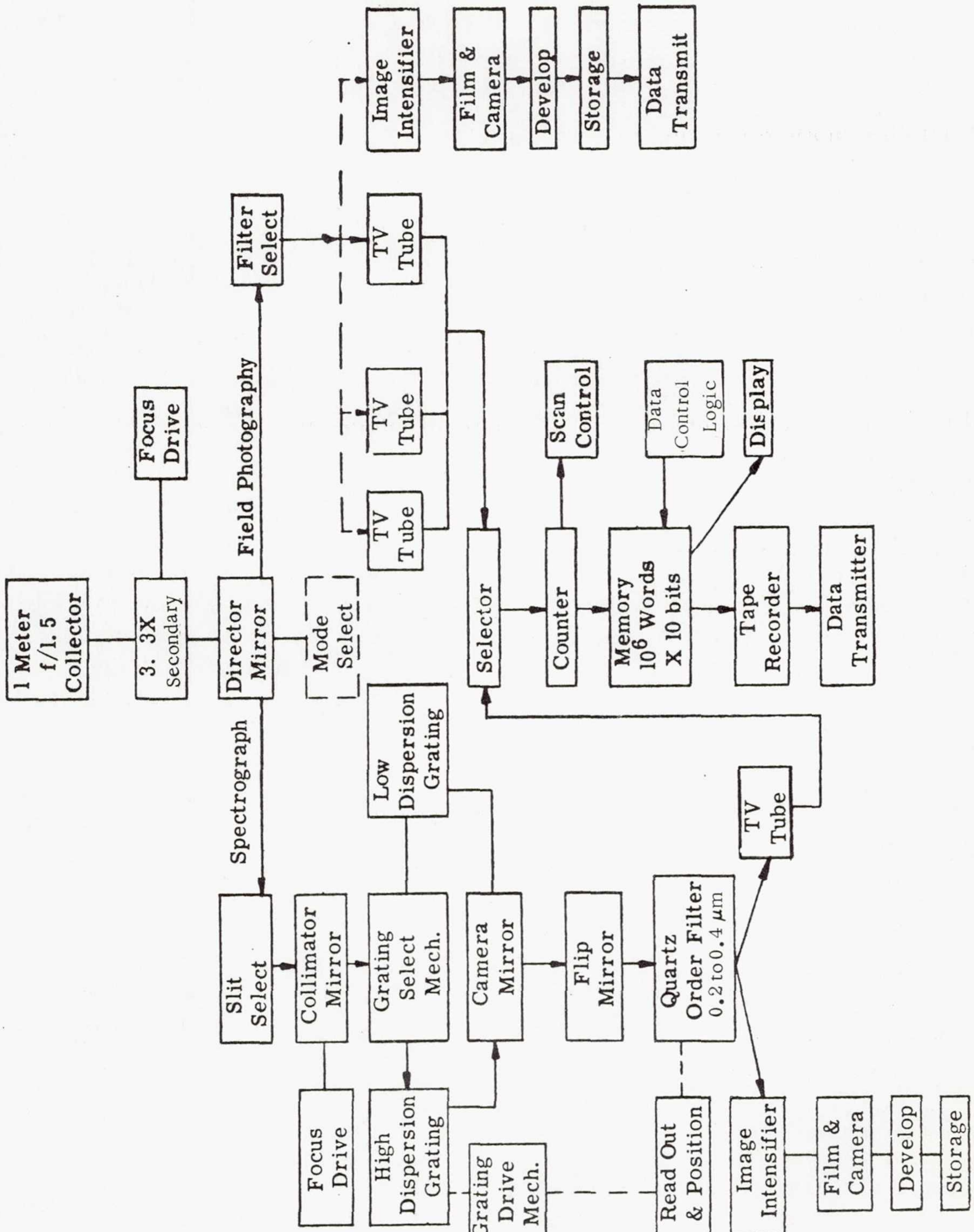


Figure 4-4. Telescope Block Diagram

After the narrow-field UV telescope is extended from its hangar, initial pointing is accomplished by the altitude and azimuth drives. The telescope and instrument package are gimballed on an azimuth table and altitude yoke arm. The table can rotate $\pm \pi$ rad ($\pm 180°$) and the yoke arm can swing the telescope $\pi/2$ rad (90°) down from its zenith. Thus, the telescope may be deployed and pointed on command, anywhere in its hemisphere.

The telescope and spectrograph assembly is mounted on a roll ring contained in the inner gimbal ring. The roll ring drive permits $\pm\pi/2$ (90°) rotation of the telescope to orient the slit aperture of the spectrograph as required by the experimenter. The inner and outer gimbal rings are mounted on the altitude yoke arm and provide the pitch and yaw axis for dynamic pointing during the experiment exposure time. To make this pointing possible, an offset tracker, roll tracker, and three rate-integrating gyros are mounted on the inner gimbal ring. Also mounted to the inner gimbal and shown deployed in Figure 4-2 is a retractable light shade for the telescope.

The telescope, gimbals, yoke and azimuth table are mounted on an elevator platform. When the system is stowed and the hatch closed, the azimuth drive may be operated for servicing, testing, and positioning of cameras for film replacement. After the hatch is opened, the platform is raised to deploy the telescope. It is raised by a cable drive system to a fixed stop which positions the platform in height and rotationally so that the deployed position relative to the coordinate axis of the spacecraft is repeatable within minutes of arc. The platform is locked in attitude in both the deployed and stowed positions to prevent movement of the system due to inertial effects.

Figure 4-3 is a mechanical layout of the telescope and instrument package. The telescope is a 0.94-m (37-in.) clear aperture f/5.25 Cassegrainian design. As shown in Figure 4-3, the collected energy is directed to one of the field cameras or to the spectrograph camera.

The Cassegrainian field camera uses a beam deflector to divert the collected energy to one of four field cameras or allows it to pass undisturbed to the spectrograph field stop aperture. The beam passes through adjustable aperture slides and the diverging beam is returned collimated by the collimating mirror to a grating (fine or coarse). It is reflected (and dispersed) to the camera mirror which refocuses the beam. The beam is then reflected by a pickoff mirror to the spectrograph camera.

One of the spectrographs is an f/5 instrument capable of monochromatic imagery within a total field angle of 0.0384 rad (2.2 deg) with a spectral resolution of 2×10^{-11} m (0.2 Å) while maintaining a spatial resolution of 5×10^{-6} rad (1 arcsec).

The control console, containing all of the switches and indicators necessary to monitor and command the telescope, is located in the supporting vehicle or space station. An

alternative control point with equivalent remote control capability is located at the ground-based UV stellar astronomy experiment control center. The typical control console provides:

a. Deployment and Pointing Controls and Readouts - automatic and manual operation.

b. Data Controls and Readouts - for astronaut monitoring.

c. Cathode Ray Tube - permits the astronaut to view and evaluate the image that is being recorded by the detector tubes, or the data from the detector tubes that has been stored in the memory. It is an invaluable aid in determining when the data-taking is complete and whether a picture is suitable for transmission in greater detail to the ground station.

4.2.1.1 Structural Configuration. The Cassegrainian telescope is contained in the two forward structures, i.e., the telescope tube and main casting. See Figure 4-5.

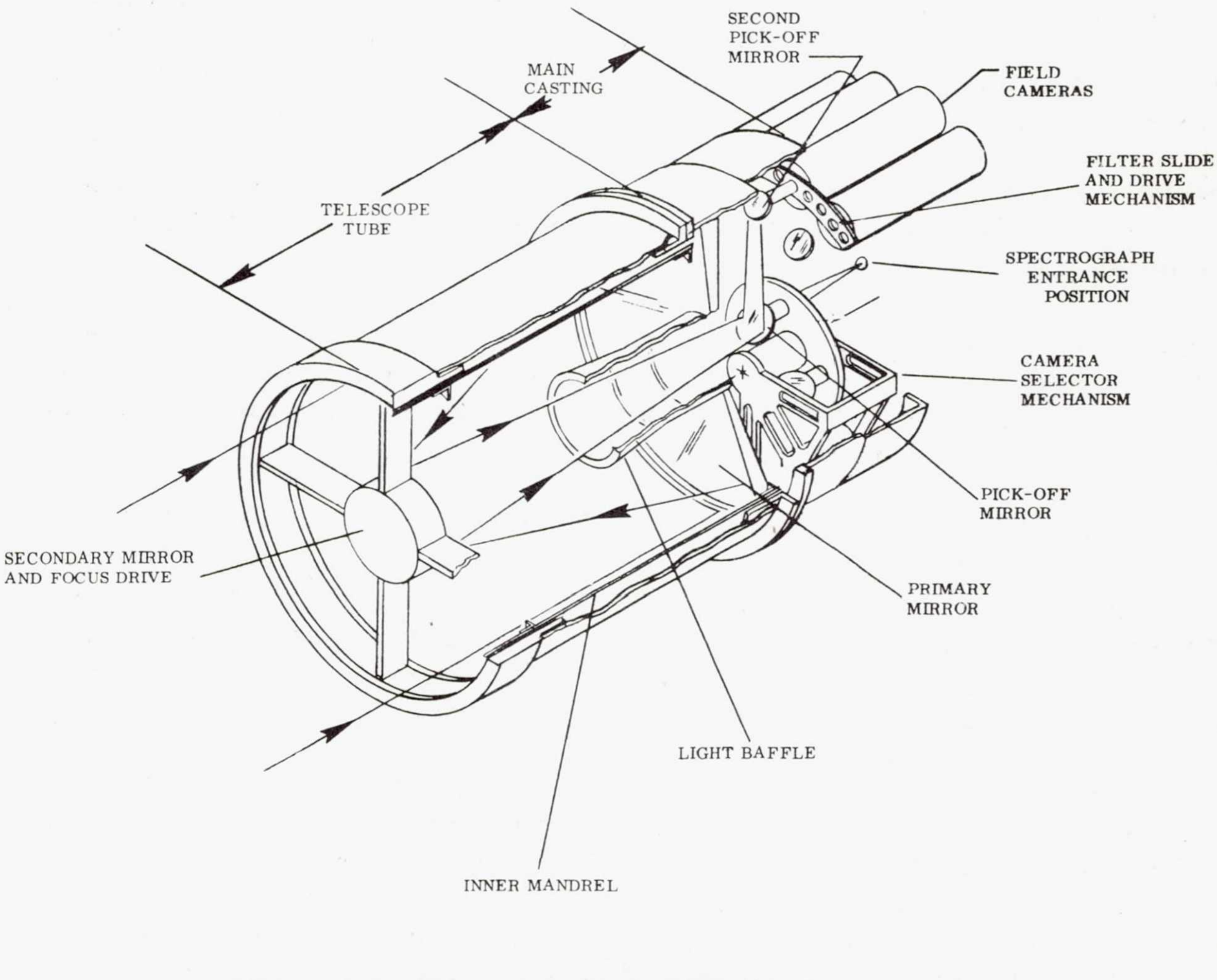


Figure 4-5. Cassegrain Telescope and Field Camera

The telescope structure is a sheet metal tube connected to forward and rear ring castings. The tube assembly will have the structural integrity to permit testing in a one-g environment as well as use in a zero-g environment. In particular, the changes in optical axis due to gravity effects (from one-g to zero-g) and launch loads will be within optical tolerances and/or compensated for during tests.

The secondary mirror and focus drive assembly is mounted on vanes attached to the forward ring. An inner mandrel is inside the structural tube. Outside the tube, but not shown, are an outer sheath and thermal insulation.

The inner mandrel and secondary mirror assembly will contain appropriate "knife-edge rings." The secondary housing will also be thermally insulated.

The telescope tube section is flange-mounted to the main casting. The main casting provides the connection to the gimbal system and contains the Cassegrainian field camera instrumentation. It also serves as the primary mirror cell.

The primary mirror is mounted on a tangent bar suspension to the main casting. The tangent bar assemblies provide the three-point mount and adjustments for optical alignment during initial assembly. The rear of the main casting provides the mounting for the spectrograph instrument package.

The field camera instrumentation requires a camera selector mechanism, diverting mirrors, filter selector mechanism and mounts for up to four cameras (film or TV, interchangeable in all four positions).

4.2.1.2 Cassegrainian Camera Selector Mechanism. The Cassegrainian camera selector mechanism is mounted to the main casting in a quadrant opposite to the field cameras. Its purpose is to switch the beam from the spectrograph entrance position to one of four possible cameras for field photography or imaging.

A wheel is mounted on a shaft with at least a 30.5 cm (12 in.) bearing span. The wheel has five positions which may be selected. One position is a clear hole permitting the Cassegrain beam to pass directly to the spectrograph instrumentation. At each of the four remaining positions is a deflecting mirror which directs the beam to its corresponding camera. The optical paths are shown in the left-hand view of Figure 4-6. The matching positions (mirrors "A" to camera "A", typical) permit direction of the beam without interference.

The wheel is driven by a torque motor and positioned within 2.02×10^{-3} rad (7 arcmin) by a multispeed resolver. A solenoid-controlled plunger is then inserted into a tapered hole, locating the wheel in position repetitively within 2.9×10^{-4} rad (1 arcmin) of wheel rotation. Thus, considering the 30.5 cm (12 in.) span, if the shaft-bearing radial play is limited to 2.54 μm (0.0001 in.) the maximum shift of the image on the focal plane of the camera is less than 38.1 μm (0.0015 in.) or 7.28×10^{-6} rad

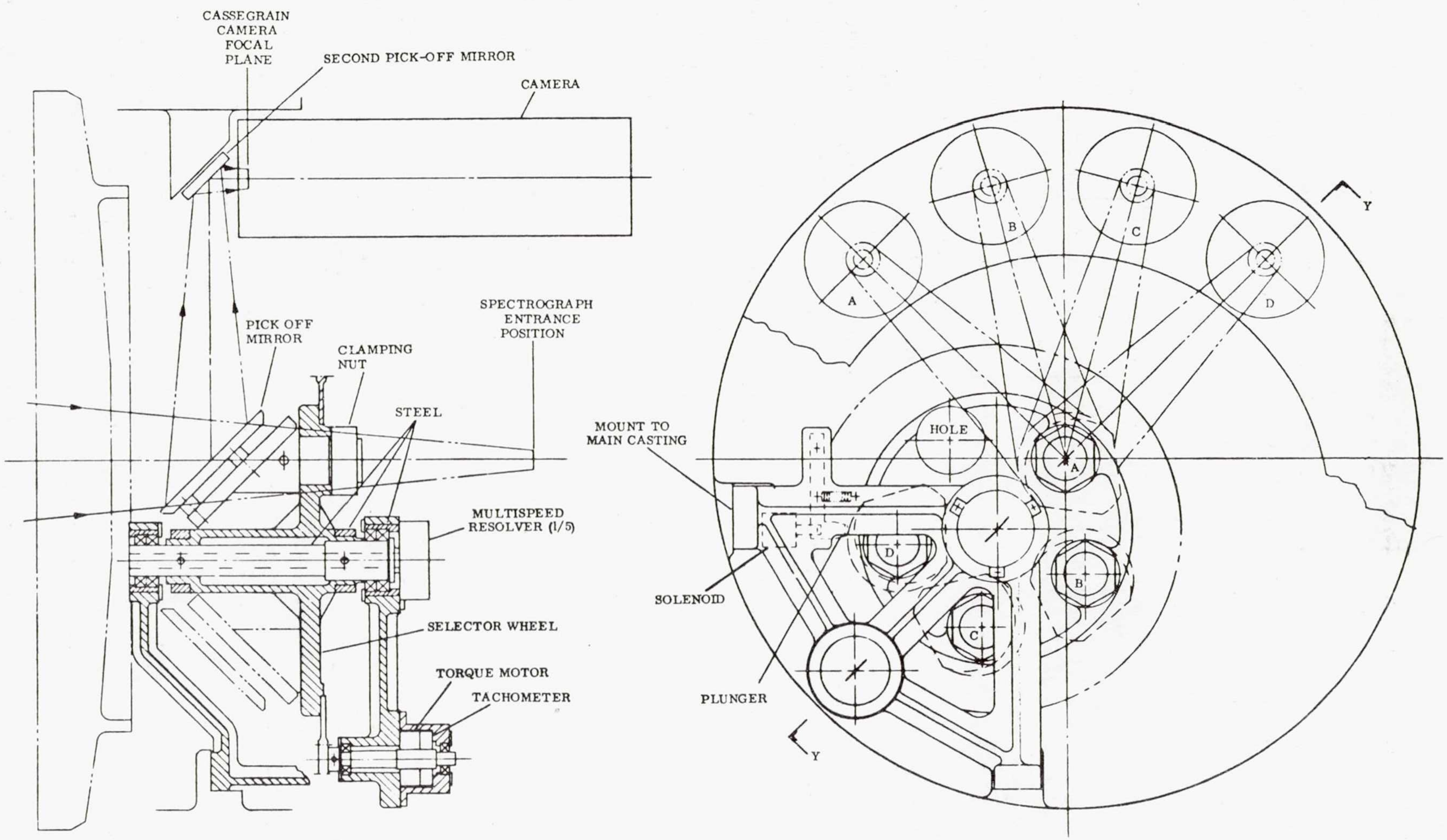


Figure 4-6. Cassegrain Camera Selector Mechanism

(1.5 arcsec) of image. However, since the solenoid plunger is pressed into a taper and gives a radial load to the bearings, the image jitter will be virtually zero.

Structurally, the shaft is mounted in an aluminum casting which is fastened to the main casting. To maintain radial-play requirements throughout the temperature range of operation, a steel shaft is used with steel sleeves to clamp the wheel to the shaft and provide bearing mounting.

The pick-off mirrors are mounted on three points to a shaft. The three-point mount is adjusted to direct the energy at right angles to the primary optical axis to a second pick-off mirror. The shaft is clamped to the wheel and may be rotated to positioning. The second pick-off mirror is also adjusted to reflect the image to the detector surface of the camera.

The filter selector mechanism is mounted to the main casting and provides for the selection of one of four possible filters for each of the cameras.

4.2.1.3 Camera Mounting. All cameras, TV and film, are interchangeable in position and are clamped in place. Figure 4-7 shows the clamping of the field cameras.

4.2.1.4 Telescope Gimbal Mount. The telescope is mounted to the spacecraft on a five-degree-of-freedom mount as shown in Figure 4-8. The telescope tube is mounted on a roll ring contained in the inner gimbal. The roll ring drive, also mounted on the inner gimbal, drives a sector gear mounted on the telescope. This provides $\pm \pi/2$ rad ($\pm 90°$) rotation for proper orientation of the aperture slit on the primary optical axis (POA).

The inner and outer gimbals are mounted on the altitude yoke arm and provide the pitch and yaw axis for target tracking during the experiment exposure time. To make this tracking possible, an offset fine guidance (OFG), a roll tracker, and three rate-integrating gyros are mounted on the inner gimbal ring (see Figure 4-8).

Initial pointing is accomplished by the altitude and azimuth mount. The altitude yoke arm may be positioned $\pi/2$ rad (90°) down from the zenith (stowed configuration) by the altitude drive. The yoke arm is mounted on an azimuth table which may be rotated $\pm \pi$ rad ($\pm 180°$) by the azimuth drive. Thus, the telescope may be deployed and pointed on command, anywhere in the hemisphere.

4.2.2 WIDE-FIELD UV TELESCOPE. This wide-field facility consists of a UV telescope and three instruments. The all-reflecting telescope is mounted on an ATM-type stabilized platform suitably modified for stellar orientation. The excellent imagery and wide field of view afforded by this telescope (5×10^{-6} rad or < 1 arcsec resolution images over a 0.174 rad or 10 deg field diameter) suit it ideally for survey work in the far ultraviolet. Operating at f/3 with a primary aperture of 33 cm (13 in.), the instrument may be considered a second-generation survey telescope capable of producing detailed line spectra.

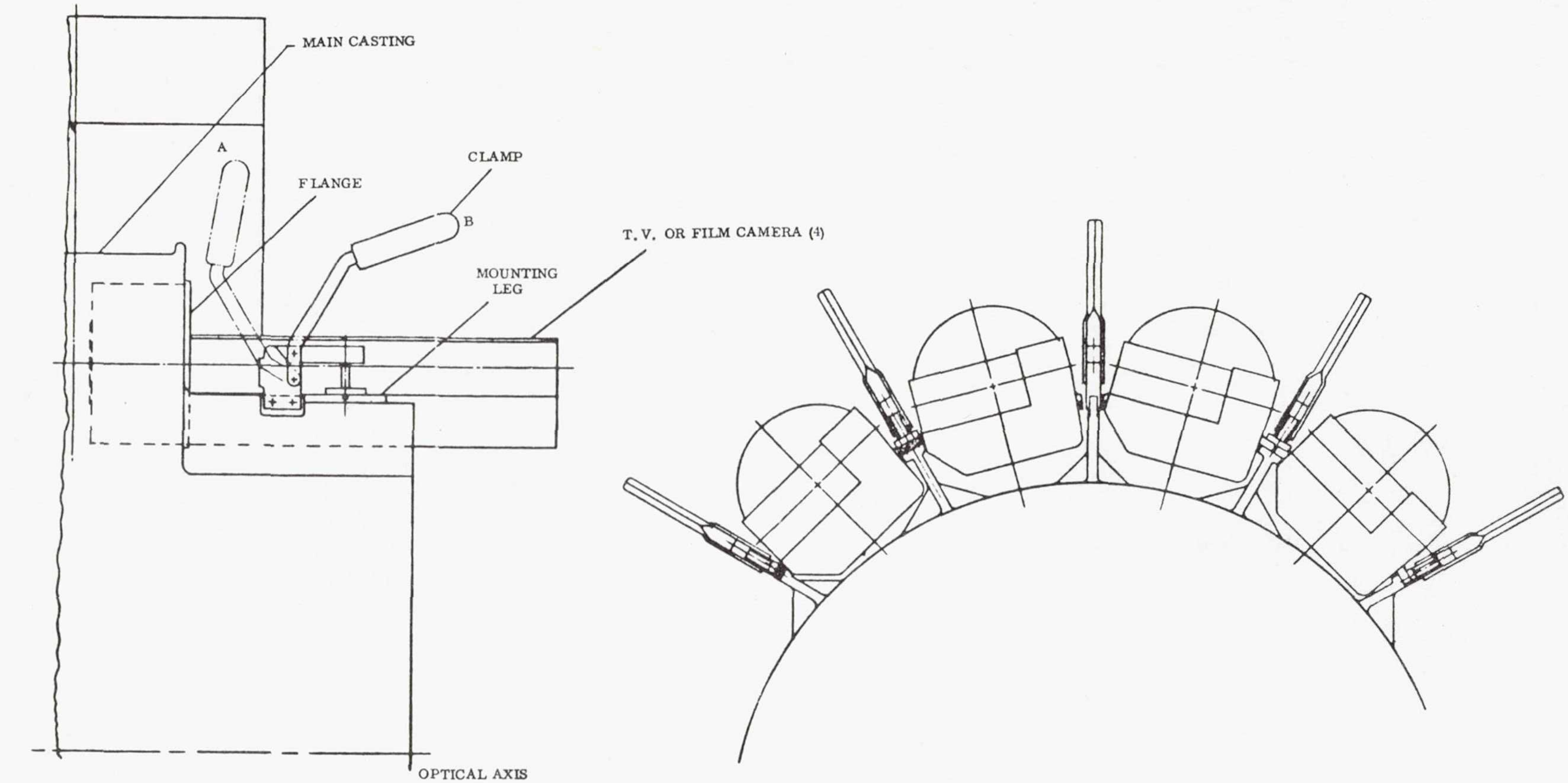


Figure 4-7. Cassegrain Field Camera Mounting

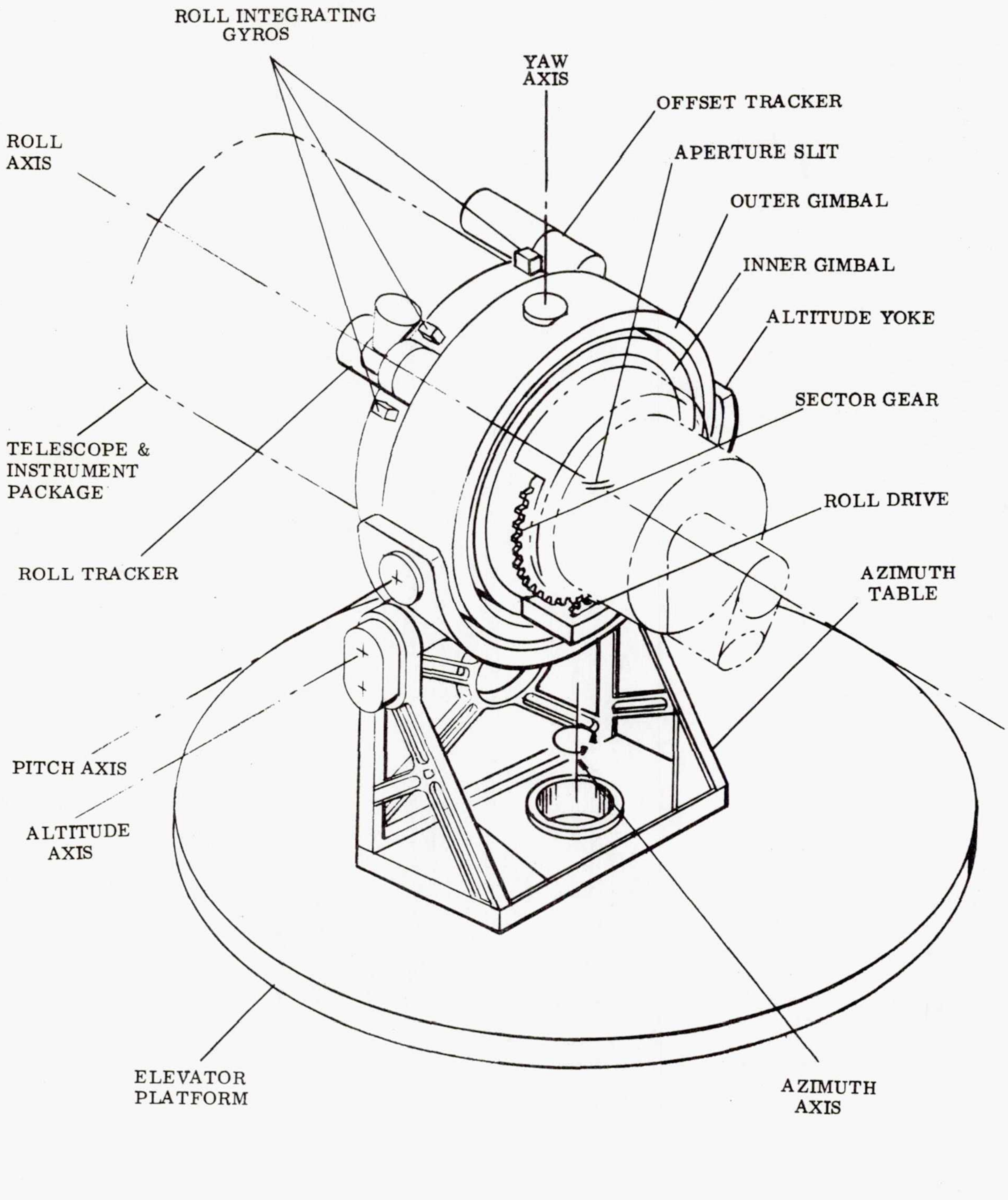


Figure 4-8. Telescope Gimbal Mount

The telescope is used with a combination electronic imaging and film camera assembly. Telescope imaging equipment is capable of photographing the sky in the range of 4×10^{-7} to 9×10^{-8} m (4,000 Å to 900 Å). Stars greater than $m_V = 8$ can be recorded with a single exposure of 2 hours duration. Images and spectra are both obtained. Basic characteristics of the telescope are given in Table 4-4.

Table 4-4. 0.3-Meter UV Wide Field Stellar Telescope Parameters

Aperture	0.3 m
Primary focal length	0.91 m
Effective focal length	0.91 m
Total field of view	0.174 rad (10°)
Angular resolution on axis	1.2×10^{-6} rad at 1.2×10^{-7} m (0.25 arcsec at 1,200 Å)
Poorest in field of view	2.4×10^{-6} rad at 1.2×10^{-7} rad (0.5 arcsec at 1,200 Å)
Obscuration of aperture	27%
Minimum wavelength	9×10^{-8} m (900 Å)
Maximum wavelength	2×10^{-8} m (2,000 Å)
Primary f/No.	1.46
System f/No.	3
Scale at system focal plane	$1.095 \times^{-3}$ rad (226 arcsec)/mm
Resolution at system focal plane	235 lines/mm
Linear field of view at system focal plane	152.4 mm

	Mass, kg	Weight (lb)	Volume m^3	Volume (ft^3)	Envelope m	Envelope (ft)
Telescope	309	680	2.86	87.0		
Combination Camera	22.7	50	0.017	0.6		
Film Magazine	9.1	20	0.017	0.6		
Gimbal Support & Mount	113	250	0.23	8.0		
	454	1,000	2.72	96.2		

The instrument (Figure 4-9) utilizes a corrected secondary mirror rather than a thin refractive correcting plate at the aperture of the spherical collecting mirror. The instrument has an aperture of 0.3 m, a focal length of 0.9 m, a 150-mm film format with a phosphor-coated fiber-optic field flattener and image converter permitting the use of an electronic imaging tube with a backup film camera. The field of view thus provided approaches 0.174 rad (10°).

The telescope housing is mounted by means of three-axis gimbals to the spacecraft. Guidance is provided by means of gimballed star trackers for acquisition and roll reference and a boresighted telescope with a fine guidance sensor to maintain precise pointing during exposure. See Figure 4-10 for gimbal configuration.

A sunshade extendable after deployment permits the telescope line of sight to be directed closer to the sun than would otherwise be possible.

4.3 EXPERIMENT REQUIREMENTS SUMMARY

Table 4-5 presents the integrated requirements of the two groups of UV stellar survey experiments. Each of the two UV facility items can be utilized to accomplish one experiment at a time. Hence, the instruments will be arranged to operate independently as well as to occasionally observe the same region of the celestial sphere at the same time.

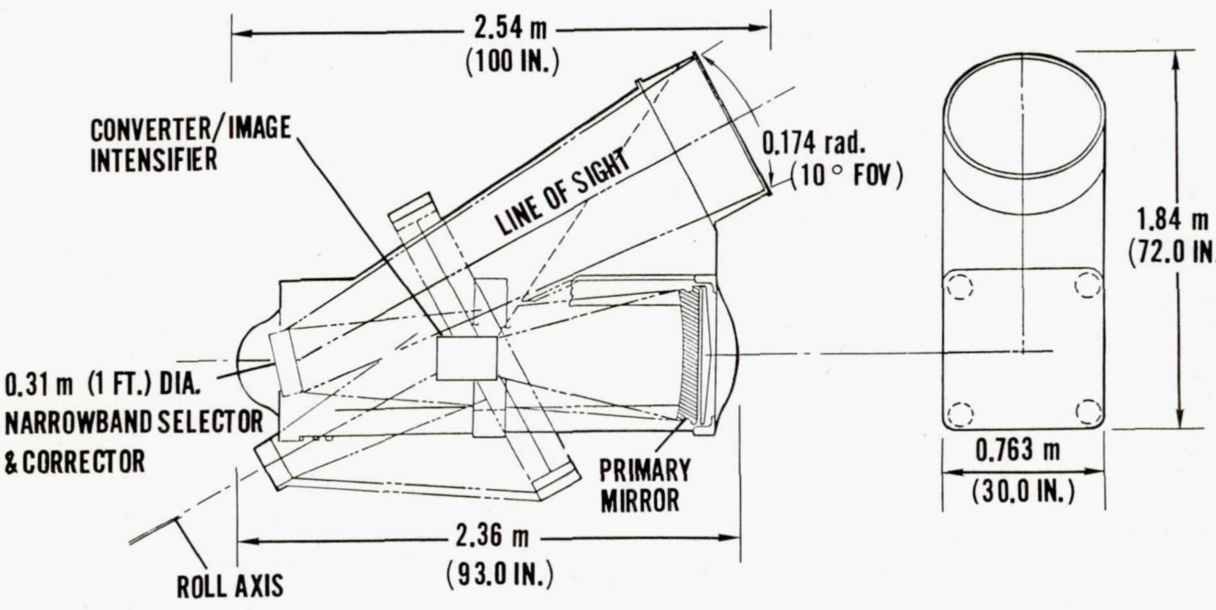


Figure 4-9. 0.3-Meter UV Wide Field Stellar Telescope

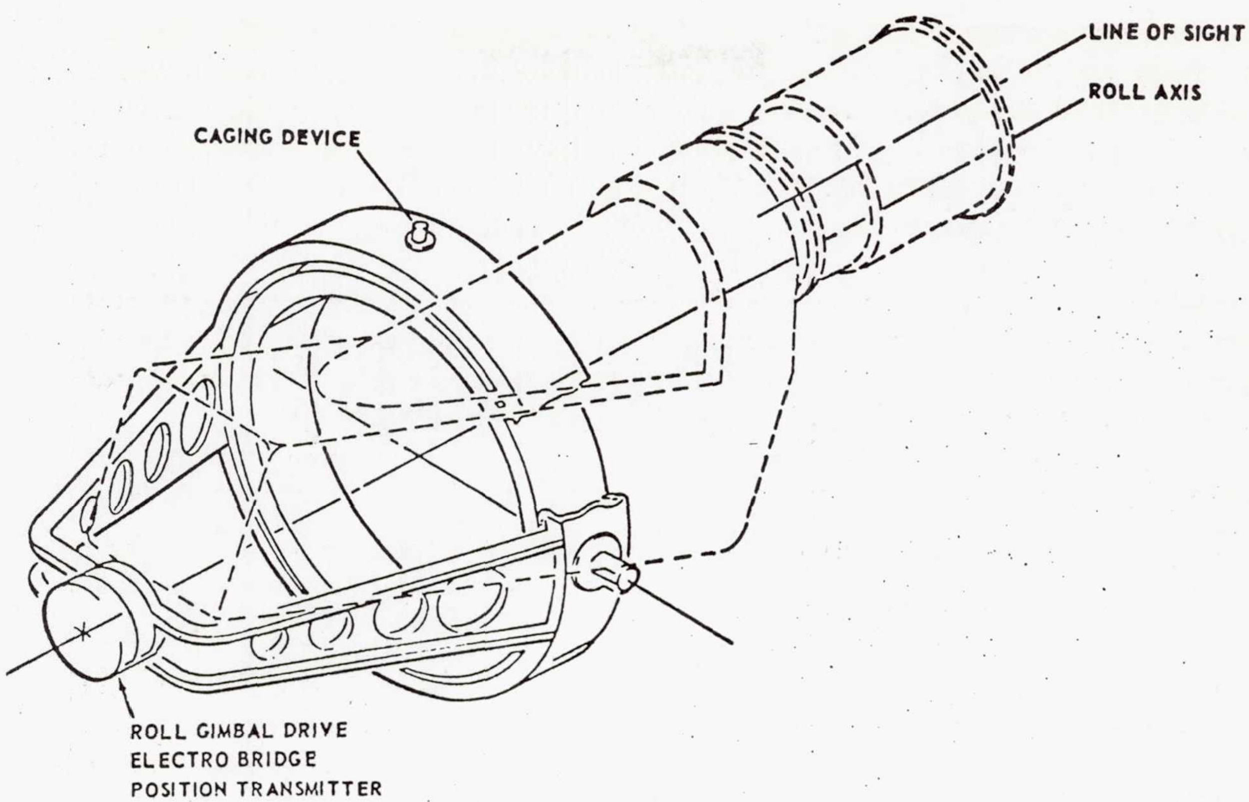


Figure 4-10. Telescope Mount Roll Gimbal

4.4 EXPERIMENT PROGRAM

4.4.1 NARROW-FIELD UV TELESCOPE EXPERIMENTS

4.4.1.1 Scientific or Technical Goals. Objectives of the narrow field UV telescope experiments are as follows:

a. Spectrally selective imaging of galactic emissions, star clusters, and nearby galaxies, as well as planets of the solar system.

b. Slitless spectrography of planetary and emission nebulae.

c. Spectrometry of selected stars, brighter quasars and novae.

d. Information on performance of the 0.94-meter gimballed telescope enabling further development of the design for interplanetary spacecraft use.

As space operations with the narrow-field UV telescope are accomplished, techniques will be developed to reduce the manhours required for alignment, calibration, reference star acquisition, stellar object location, and maintenance. Some of the improvement will come from retrofit of improved instruments and automated telescope accessories at about two-year intervals.

Table 4-5. UV Stellar Survey Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
4.4.1 Narrow Field UV Telescope Experiment	1100 (2420) plus pressurized service housing wt. 2040 (4500)	8.46 (300) including elevator 38.3 (1356) stowed	$1.53 \times 1.53 \times 3.66$ ($5 \times 5 \times 12$) plus projecting gimbals 3.66×3.66 ($12D \times 12L$) pressurized servicing housing	Average: 266 Peak: 300 Standby: 144	Astronomer/ Astrophysicist/ Astronaut	Temp Limits: 289 to 290° K Ops Atmosphere: $0-10^5$ N/m^2, $<1.33 \times 10^{-4}$ N/m^2 ($0-15$, $<10^{-6}$ torr) operating Gravity Level: $<10^{-3}$ preferred Radiation Sensitivity: < 1 millirad/hr	Setup: 10 Ops Cycle: 13.5/avg. sequence Maintenance: 16/180 day to 16/week*	Picture Elements Per Image: 10^6 Images/Sec: 6.95×10^{-5} to 1 Digital Picture Data: 8×10^6 bps Non Imaging Data: Command: <100 bps Science/Exps: <2000 bps Housekeeping: ~200 bps	Pointing Accuracy: Instrument $<5 \times 10^{-6}$ rad (<1 arcsec) Supp. spacecraft 8.7×10^{-3} rad (30 arcmin) Pointing Stability: $<5 \times 10^{-6}$ rad/obs time (<1 arcsec/ obs time) Max. Slew Rate: 0.1 rad/min (6°/min) Min. Slew Rate: $<5 \times 10^{-6}$ rad/sec (<1 arcsec/sec) Pointing Hold Time: 2400 to 14,400 sec	Desired Incl: 28° to 70° Acceptable Incl: Any Desired Alt: 370 to 670 km (360 n. mi.) Acceptable Alt: 370 to 740 km (200 to 400 n. mi.)	Retractable into pressurized service housing $>2.5 \times 10^8$ bits rapid access storage Apportionment of stabilization requirement between vehicle and 3-axis gimbals required
4.4.2 Wide Field UV Telescope Experiment	431 (950) plus gimbals elevator service hous ng weight	2.69 (~95) plus gimbals elevator service housing volume 38.3 (1356)	Rectangular Prism w/off axis cylinder $0.91 \times 1.07 \times 2.75$ ($\sim 3 \times 3.5 \times 9$) may be stowed in 3.66×3.66 ($12D \times 12L$) pressurized service housing	Average: 320 Peak: 325 Standby: 120		Temp Limits: 289 to 290° K Ops Atmosphere: $0-10^5$ N/m^2 $<1.33 \times 10^{-4}$ N/m^2 (015, $<10^{-6}$ torr) pref. Gravity Level: $<10^{-3}$ operating Radiation Sensitivity: <1 millirad/hr	Setup: 4 Ops Cycle: 1.6 to 4.86 Maintenance: 4/week	Picture Elements Per Image: 1.6×10^7 to 10^9 available, prefer handling 1.6×10^7; min: 10^6 Images/Sec: 6.95×10^{-5} to 1 Digital Picture Data/Image: 7×10^9 bits available; preferred data handling 1.12×10^8; 7×10^6 bits min/image Non Imaging Data: Command < 100 Science/Exps: < 1000 bps Housekeeping: < 100 bps	Pointing Accuracy: 5×10^{-6} rad (1 arcsec) ref to 2.4×10^{-5} rad (5 arcsec), supp. spacecraft 8.7×10^{-3} rad (30 arcmin) Pointing Stability: Preferred: 2.4×10^{-6} rad (0.5 arcsec) Acceptable: 5×10^{-6} rad (1 arcsec) Max. Slew Rate: 0.1 rad (6°/min) Min. Slew Rate: $<5 \times 10^{-6}$ rad (<1 arcsec/sec) Pointing Hold Time: 360 to 14,400 sec	Desired Incl: 28° to 70° Acceptable Incl: Any Desired Alt: 370 to 670 km (250 to 360 n. mi.) Acceptable Alt: 370 to 740 km (200 to 400 n. mi.)	Optionally retractable into pressurized housing to enable servicing For wide field, best results with film Limited fields available via all-electronic imaging at best resolution

4.4.1.2 Description.

4.4.1.2.1 Focus and Alignment. At the best focus position for this telescope (flat focal plane), the geometrical spot sizes are equal to 2.9×10^{-3} rad (10 arcmin) off-axis and on-axis. The minimum spot size occurs between those two field angles; the on-axis spherical aberration balances with the off-axis aberrations (coma and astigmatism) at the best focus location. Because of the wide field of view, 5.8×10^{-3} rad (20 arcmin), and basic telescope limitations (to permit UV transmission there are no refractive elements) the geometrical aberrations are 50 times the size of the diffraction effects. At 2×10^{-7} m (2,000 Å), the well-known equation for pure diffraction* predicts a diffraction spot diameter of 0.0025 mm (0.0011 in.). The average geometrical spot size (85 percent of the energy) of the telescope is about 0.0216 mm (0.00085 in.) diameter. The 10 percent central obscuration of the telescope has a small and practically negligible effect on the system resolution and modulation transfer function (MTF) as is typical of similar Cassegrainian or catadioptric arrangements. Thus, it can be seen that performance of the telescope is essentially set by the geometrical aberrations, and diffraction effects are of secondary importance. The above is true as long as the smoothness and conformity of the mirror surfaces meet the requirements.

The shapes of the Cassegrainian field camera images give a very clear picture of the residual telescope aberrations. The on-axis image has its smallest size at 0.1016 mm (0.004 in.) beyond the paraxial focus. The somewhat larger image at the +0.001 inch (0.025 mm) location is due to residual overcorrected spherical aberration, largely contributed by the fifth- and seventh-order terms of the spherical aberration (SA) series expansion. The 2.9×10^{-3} rad (10 arcmin) off-axis image is clearly astigmatic from its elliptical shape. With the telescope focus at +0.025 mm (+0.001 in.), the major axis of the ellipse is in the tangential direction (as it should be when the focal plane is beyond the sagittal astigmatic focal surface). The hole due to the central obscuration is clearly evident in the off-axis image, as is the negative field curvature present in the system. The hole tends to lower the MTF modulus at middle frequencies, but the excellent energy concentration in the spot minimizes the importance of this effect.

Examination of the telescope spot diagram energy distributions shows that 12 percent of the energy does not get through on-axis and 10 percent does not pass through for the 2.9×10^{-3} rad (10 arcmin) off-axis images. More energy gets through off-axis because the circular secondary mirror obscuration becomes elliptical for off-axis rays and actually has a smaller projected area. The secondary mirror is slightly oversized to ensure that a maximum of the off-axis energy will get through; thus, there is no vignetting at the edge of the field. Conical baffles will be used so as not to increase the obscuration and still provide protection from stray light (starlight, sunlight, earthlight, moonlight, and artificial sources).

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*Linear diffraction spot diameter = 2.44 (λ) (f/No.)

The telescope has an MTF greater than 40 line pairs/mm (1,000 line pairs/inch) at an average response of 20 percent at the Cassegrain focal position.

A preliminary tolerance analysis of the positioning of the optical elements is performed using a 10 percent spot size growth at the telescope focal plane for a performance criteria. The position of the secondary mirror along the optical axis must be maintained within ±0.025 mm (±0.001 in.) from a position 0.025 mm (0.001 in.) beyond the paraxial focus which is the best compromise for a flat focal plane for the 5.8×10^{-3} rad (20 arcmin) diameter field. The secondary focus drive capability makes maintenance of this tolerance feasible.

The decentration tolerance using the same image growth criteria dictates that the secondary mirror be positioned within a 0.025 mm (0.001 in.) diameter circle. A 20 percent image growth is acceptable from the system performance standpoint and would indicate a permissible secondary axis decentration within a 0.1 mm (0.004 in.) circle. The effect of decentration will cause improvement at some points of the field and degradation in other areas. Distribution of the energy in the spot makes it difficult to make a clear-cut evaluation of the image growth resulting from decentration without more extensive investigations.

If any of the optical elements, such as the secondary mirror, should shift relative to the primary mirror along the optical axis, the image at the cameras would become defocused. This change can occur as a result of launch stresses or temperature changes. Thus, a focusing mechanism is provided to refocus the image at the cameras by moving the secondary mirror in either direction along the optical axis. The focal plane may be checked and adjusted manually or remotely.

To perform a focus adjustment manually, a microscope fixture can be placed in each of the Cassegrainian camera positions to view the focal plane. The secondary focus drive can then be stepped on the optical axis until the best focus is observed. This method will be used for initial alignment and the best focus located at mid-travel of the drive. If it is used in space, a collimated light source or a star simulator will be used and the alignment performed in a shirtsleeve environment or IVA (i.e., the instrument stowed and hatch closed).

Focus sensing can be done remotely by using one of the TV cameras and viewing the image on the display monitor. Thus, the instrument can be deployed and the focus checked. Since the resolution of the TV display is poorer than the visual method, unless electronically magnified, the best focus position may not be evident. The method used will be to step the focus drive in one direction through best focus, noting the step number where it stops. Then the drive is reversed and again viewed for stepping through focus and noting the step number. The best focus should then be midway between the two readings.

Figure 4-11 shows the optical path of the Cassegrainian field camera optics. The telescope tube and main casting are bench assembled and the optical path to the Cassegrainian focal position is determined and aligned by using standard alignment techniques. The mirrors of the camera selector wheel are on an adjustable three-point mount. The mount is also adjustable on an axis parallel to the primary optical axis. The second pick-off mirror is also adjustable. Thus, the image plane is at a fixed distance "A" from the camera mounting surface and will be made identical for all four camera positions. Each camera will be made so that the corresponding distance (A) from the image plane to the mounting surface of the camera is the same. This enables interchangeability of cameras in all positions and with each other.

4.4.1.2.2 Guide Stars Acquisition. It is desirable to achieve maximum utilization of the astronaut and equipment. If the primary acquisition mode were manual, a significant percentage of the astronaut's time would be spent in acquiring the necessary guide stars. Therefore, the primary mode of acquisition should be automatic. This experiment is intended to test the process and provide optimization data for adjustments.

The correlation between automatic acquisition and the use of spacecraft-generated orientation information can be seen by an examination of Figure 4-12. Assume that the target (at which the telescope must be pointed) lies along the R axis and, for the sake of convenience, that the spacecraft yaw, telescope azimuth and telescope yaw axes are along the Y axis of Figure 4-12. Also assume that the spacecraft pitch, telescope altitude, and telescope pitch are along the X axis. The azimuth and altitude drives can be positioned to within 4.37×10^{-4} rad (1.5 arcmin) and the telescope yaw and pitch to within 1.45×10^{-4} rad (0.5 arcmin). If spacecraft-generated orientation information, accurate to 2.9×10^{-4} rad (1 arcmin) or better, is used, the maximum positional error in the X and Y axes (Figure 4-12) will be 8.7×10^{-4} rad (3 arcmin). This assumes that all of the errors are maximum and additive – a highly unlikely occurrence. Since the acquisition field of the fine guidance is 2.3×10^{-3} rad by 2.3×10^{-3} rad (8 arcmin by 8 arcmin), the guide star will always be within the acquisition range of the fine guidance and automatic acquisition is guaranteed.

The following information must be entered into the computer in inertial space coordinates:

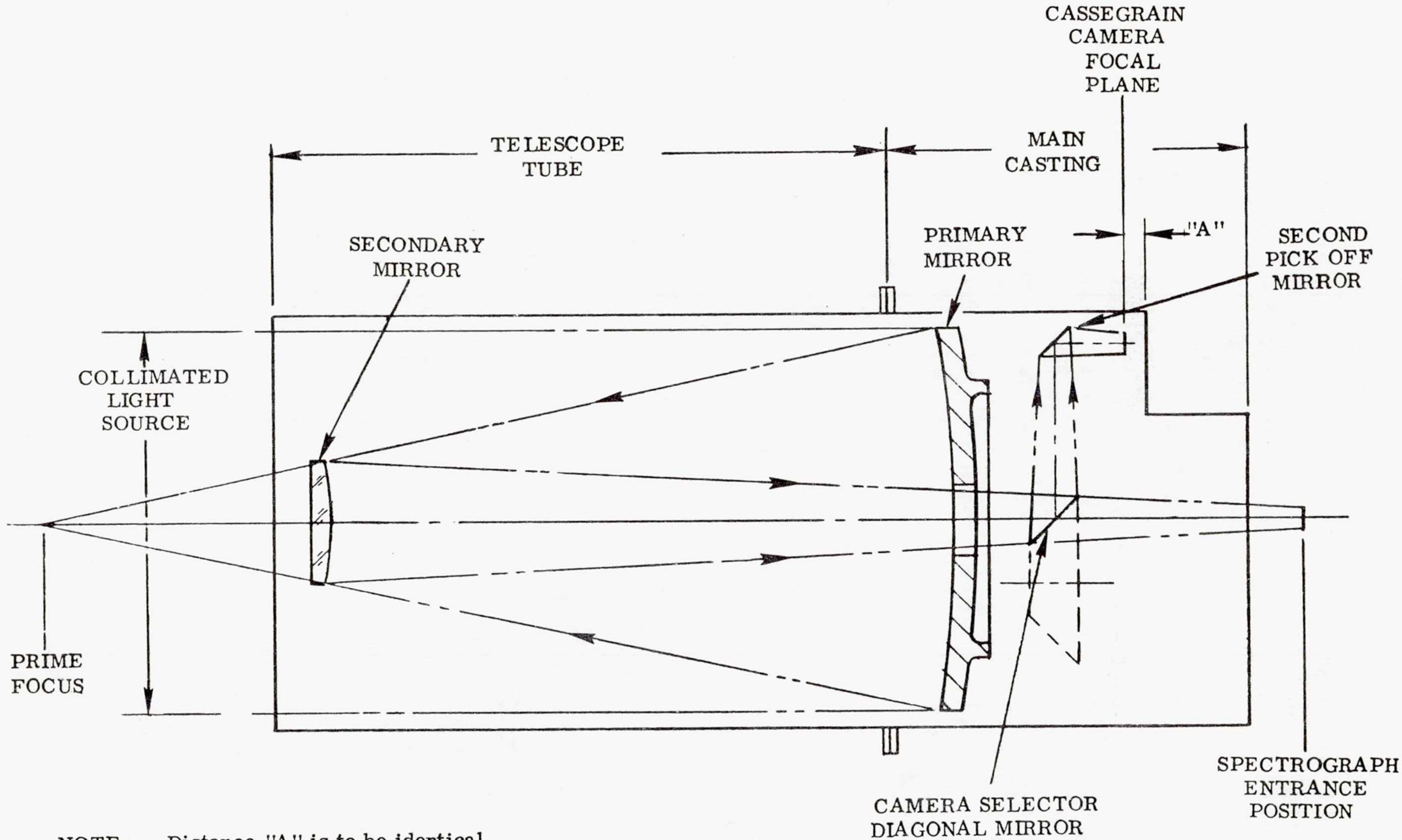
a. Target coordinates.

b. OFG guide star coordinates.

c. Roll Tracker guide star coordinates.

d. Required roll position(s) of the telescope.

4.4.1.2.3 Stellar Object Acquisition and Location. After deployment of the telescope, the acquisition and guidance system points the telescope, then tracks the target anywhere within a hemisphere. Coarse stabilization is provided by the



NOTE: Distance "A" is to be identical for all camera positions (4) and on each camera.

Figure 4-11. Alignment of Cassegrain Telescope and Field Camera Optics

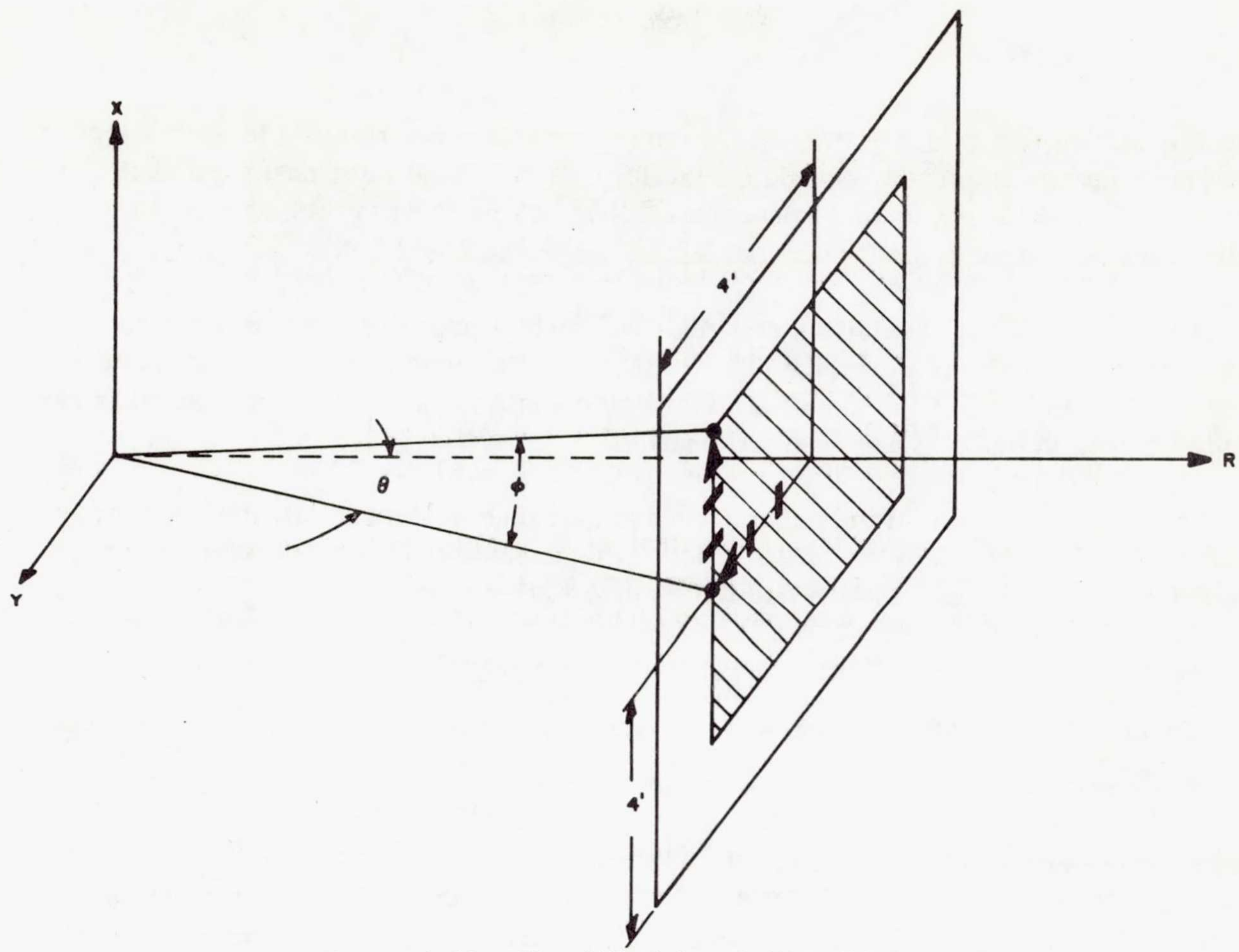


Figure 4-12. Simplified Acquisition Diagram

spacecraft. Intermediate pointing is accomplished using an alt-az mount to point and place guide stars in the field of view of an offset tracker and a roll tracker. These trackers acquire and then guide with a guidance error of less than 5×10^{-6} rad (1 arcsec) 95 percent of the time (2σ). The acquisition and guidance system is automatic and provides status information to the astronaut and/or ground controller. The system also provides nonautomatic operation for manual verification and/or malfunction overrides.

The acquisition and guidance process performs two functions: pointing and tracking. Pointing utilizes the alt-az mount and equipment to coarse-point the telescope in order to acquire any target within a celestial hemisphere, after which control is transferred to the offset fine guidance (OFG) for fine pointing the telescope with the gimbal system. Tracking maintains the target stability at the focal plane of the telescope in order to prevent image smearing. This function utilizes two star trackers (OFG and roll tracker) to acquire separate guide stars and generate error signals which are processed and applied as correction signals to the telescope gimbal system. These corrections effectively fix the position of the telescope in inertial space. The guidance error will be less 5×10^{-6} rad (1 arcsec) 95 percent of the time (2σ).

The acquisition and guidance system also provides status information to the control equipment and the astronaut/ground controller. It furnishes information on such items as acquisition status and telescope attitude and pointing error, as well as indications of malfunctions (to prevent the taking of useless data).

Another feature of the acquisition and guidance system provides for nonautomatic acquisition and guidance control. The semi-automatic mode permits operation verification and can be used in case of a minor equipment malfunction. The manual mode would be used in event of a major malfunction.

Design and performance of the acquisition and guidance system is affected by spacecraft motion and the accuracy of the spacecraft-generated orientation information. Therefore, several assumptions had to be made in this area:

a. Maximum spacecraft pointing error will be 8.7×10^{-3} rad (30 arcmin).

b. Error in spacecraft orientation information will not exceed 5×10^{-6} rad (1 arcsec).

c. Spacecraft motion will be approximately sinusoidal.

The primary error detector used in the system is the OFG. Calculations made in Technical Proposal SD-270 on RFP 613-34205 indicates that to achieve a pointing accuracy less than 5×10^{-6} rad (1 arcsec), the bandwidth of the servo must be less than 1 rad/sec. To keep the bandwidth within this limit and to keep the torque disturbance errors below 1 arcsec, a rate-gyro loop was added. The addition of the rate-gyro loop is also beneficial in the event of manual acquisition and guidance. It provides the astronaut with a velocity control, which is superior to a position control for manual guidance.

The computer, utilizing the spacecraft position information, determines:

a. Required altitude and azimuth mount positioning (in relation to the spacecraft) to to point the telescope at the desired target.

b. Required position of the OFG and roll tracker relative to the telescope. This enables the trackers to acquire their selected guide stars when the telescope has been pointed at its target by the altitude and azimuth drives.

c. Required roll position of the telescope in relation to the roll gimbal.

The computer initially commands the yaw and pitch gimbals of the telescope to their center positions. This is done so that when the altitude and azimuth drives have positioned the telescope, the guide stars for the OFG and roll star tracker will be within their fields of view. If necessary, the computer then enables the roll-gimbal-positioning servo loops.

The computer then enables the OFG and roll star tracker positioning servo loops. These servos, sensing the difference between the commanded positions and the present positions of the OFG and roll tracker, then drive until the difference or error in positioning is zero. (Star tracking is not yet enabled.)

When the roll gimbal, OFG and roll tracker are in position, the computer enables the altitude-azimuth servo loop. Error signals (difference between the desired positions and present positions) drive the altitude-azimuth mount to point the telescope at the desired target.

When the altitude-azimuth servo error is within acceptable limits (coarse pointing achieved), the alt-az mount is locked in position and the OFG and roll tracker, which are used for fine pointing of the telescope, are enabled. The OFG senses the yaw and pitch error (from the offset guide star) and drives the telescope yaw and pitch gimbal servos. The roll tracker senses telescope roll motion and inserts a correction (computer calculated) into the yaw and pitch gimbal servo loops.

Roll motion of the telescope may also be sensed by using a gyro instead of a tracker. A gyro uses less power and does not depend on a line of sight to a particular star. However, gyros inherently possess a long-term drift. Therefore, to ensure accurate pointing of the telescope, the gyro drift rate or bias must be measured and removed. The gyro drift rate can be automatically measured by the roll tracker during initial telescope pointing and tracking of a target. When a drift rate has been determined, the computer will automatically switch off the tracker and switch the gyro into the telescope roll-sensing circuitry. The computer will also insert a bias into the gyro circuitry to nullify the gyro drift rate bias.

Upon completion of the pointing and tracking operations, the system is ready to begin the data acquisition phase of the experiment.

4.4.1.2.4 Electronic Imaging. No single choice of film versus electronic imaging detectors can be made for this experiment since each has its usefulness. In addition to the quality of the optical system, the resolution capabilities of the film and TV systems are dependent upon the following major parameters:

a. Observing time.

b. Filter bandwidth.

c. Pointing error.

d. Object surface brightness.

e. Image-enhancement techniques.

An example of this is shown in Table 4-6, assuming an observing time of one hour, filter bandwidth of 0.1 μm (1000 Å), and 1 σ pointing error of 3.88×10^{-7} rad (0.08 arcsec).

Table 4-6. Cassegrainian Field Camera S/N and Resolution

	Signal/Noise Ratio for Object with Surface Brightness of $19m_V$ arcsec^{-2}(3×10^{-5} photons cm $^{-2}$ arcsec^{-2} sec $^{-1}$ Å $^{-1}$)	Resolution cycles/mm (15% Response)
Image Unenhanced:		
SEC Vidicon	130	24
Film + Intensifier	47	40
Image Enhanced:		
SEC Vidicon	50	39
Film + Intensifier	32	57

In this table, film demonstrates a finer resolution capability. On the other hand, if lesser resolution is required (e.g., 24 line pairs/mm), the detectors have a better signal-to-noise ratio.

Investigations and computations have shown that the resolutions will improve for objects of large surface brightness and comparable observation times. Thus, the system provides both film and detector systems; the recording system chosen in a function of parameters a through d and the resolution requirements of the scientist/astronomer. Additionally, it provides the necessary flexibility as newer films, filters, and detectors are developed and supplied for use.

Recent development in electronic zoom cameras present a capability of a demagnification of the image and therefore an increase in photon density on the detector. Minification of the image is valuable in cases of low object surface brightness approaching the sensitivity limit of the detector system as determined by dark current in the case of electronic detector tubes and reciprocity failures in the case of film.

Automatic data processing and storage is provided for the electronic camera systems. A multiple-exposure scheme is used wherein results of successive scans are combined and stored again. At the end of an observation, the total image is transferred to magnetic tape for storage and subsequent transmission to the ground. While the observation is taken, the astronaut may view and monitor the image, as stored, at the control console.

The cameras will be capable of detecting and recording the images present at the Cassegrainian focal position of the telescope over the spectral range from 0.09 μm to 0.35 μm (900 Å to 3500 Å).

At the expense of additional attenuation of the input energy, narrow-band filter photography may be developed to use interference filters in conjunction with the UV cameras. Filters of the Fabry-Perot type, which utilize semitransparent aluminum films as the reflecting element, appear to be practical for use of telescopes. The substrate and dielectric spacer will have to be lithium fluoride for those filters in the region below 0.2 μm (2000 Å). Above 0.2 μm (2000 Å) fused silica will be satisfactory for the substrate. The peak transmission of this type of filter can be 35 percent through most of the spectral region of the telescope. The bandwidth (which depends on the reflectance) will increase with decreasing wavelength. At 1200 Å a bandwidth of 0.03 μm (300 Å) can be expected. At 0.2 μm (2000 Å), the bandwidth will be 0.015 μm (150 Å).

Image detection and storage will be accomplished by three different methods: direct film, image intensifier/converter plus film, and television. The three method are retained to offer the experimenter the greatest flexibility in achieving his scientific objective. A fourth method, intensifier/converter plus television, is still under consideration. If the technical problems of such a combination can be solved, it could extend the usefulness of the telescope. Each method of detection will be realized in a separate camera and the cameras will be selected and installed before deployment of the telescope in accordance with the objectives of a particular experiment.

Current development efforts on image tubes are aiming to produce a device with an MTF like that of film; then, the SEC vidicon does not have to be loaded like a camera, and the image may be recalled from storage and viewed as the image is being formed.

There is no reason at this time to select the film system over the electronic detector or vice-versa. Each has its own merits, and satisfies different needs. The film system possesses a better resolution, as demonstrated by its capacity to achieve a resolution of 57 cycles/mm, with a signal-to-noise ratio of 32. The SEC vidicon, at a resolution of 50 cycles/mm, has an S/N ratio of 4.2; however, at 39 cycles/mm (S/N = 50), it is comparable to film. If a lower resolution is tolerable and a larger S/N ratio is desired, the SEC vidicon exhibits a much higher S/N ratio (e.g., for a resolution of 24 cycles/mm, SEC vidicon S/N ratio is 130). However, this does not mean that the SEC vidicon system does not possess the resolution capabilities of film.

4.4.1.2.5 Backup Film Imaging. The 0.94-m (37 in.) diameter f/5.25 Cassegrain telescope provides a 5.23×10^{-3} rad (18 arcmin) image for recording by film or TV cameras. Cameras will be selected for the appropriate spectral response in conjunction with selected filters with bandwidths in the order of 1.5×10^{-8} m (150 Å). Angular resolution of the field camera is better than 5×10^{-6} rad (1 arcsec). Primary uses provided are:

a. Spectrally selective ultraviolet photography of galactic emission and reflection nubulae.

b. Spectrally selective ultraviolet photography of star clusters.

c. Direct ultraviolet photography of galaxies, brighter quasars, and novae.

The film is loaded in cassettes which are exchanged either manually or remotely. Each casette may hold as much as 800 frames of film. Manual replacement is accomplished by use of a specially designed tool. This tool is used for the cassete and also for the removal of all cameras (film and TV) during replacement and/or service.

The automatic cassette-replacement system is loaded with the telescope retracted in its hangar. This permits rapid replacement of the film because it eliminates the need for waiting many hours until the telescope temperature stabilizes for a shirt-sleeve environment. The automatic film-changing mechanism eliminates the need for EVA and also saves in the use of air required for the hangar volume to provide a shirtsleeve environment for film replacement.

Each film camera is interchangeable with each TV camera in the spectrograph and four field camera positions. It is designed so that the focal plane falls on the front surface of the image-intensifier tube when the camera is located by the locating flange and mounting legs. Figure 4-13 shows a film system camera and cassette. The image-intensifier tube is in the front end and displays the collected energy at image plane I where the film is held by platen I. The data frame is recorded at image plane D where the film is held against the prism face by platen D. The data is generated on a CRT or mechanical counters. It is relayed by a triplet lens and displayed on the face of an Amici prism.

The collected energy and data frame are recorded on 35 mm film. Recorded energy is displayed on a 25.4 mm (1 in.) diameter face of the image intensifier tube and placed in the 25.4 mm $\times$ 12.7 mm (1 in. $\times$ 0.5 in.) film area with the data occupying no more than 11.1 mm (7/16 in.) of the width. Thus, the positioning requirement of the film is $\pm$0.074 mm (1/32 in.).

The image and the data cannot be recorded simultaneously. The centers of the image and data frames are 57 mm (2-1/4 in.) apart. Thus, the image (e.g., image A) must be recorded first. The film is then advanced 38.2 mm (1 1/2 in.) and the data frame recorded (data frame A).

To perform photography with a photometry precision of 3% and a spectral resolution of 0.03 μm (300 Å) on a continuum for a surface illumination of 1.19×10^{-6} photons cm^{-2} sec^{-1} $arcsec^{-2}$ $Å^{-1}$ (13.5 mag/min^2 object), an observation time of 6.62 hours is required to obtain 1,000 events. One should not infer from this that spectrography of a continuum is impossible. If 10% spectrography (100 events) is desired, the required observation time is reduced to a practical value of 0.662 hour.

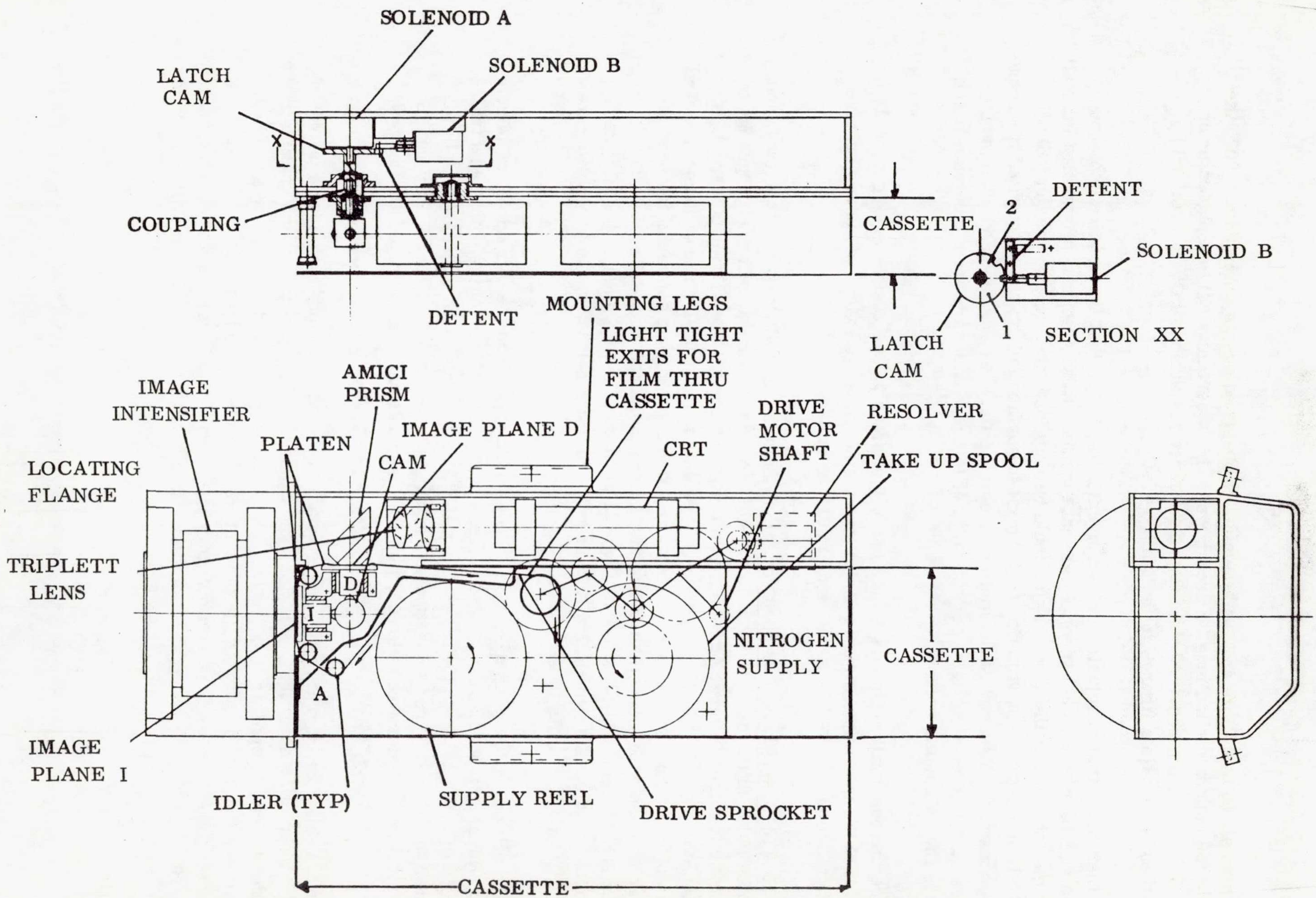


Figure 4-13. Film Camera and Cassette

In general, to use Table 4-7 for a number of observed events other than 1,000, the following approximation may be used. Since the uncertainty (Q) in a photon count N is: $Q = \sqrt{N}$, the required time for an intensity resolution of C% is obtained by multiplying the time figures in the table by $9/C^2$.

Another important conclusion evident from Table 4-7 is that the required observation time varies over a wide range as a direct function of the system configuration utilized and the intensity of the source. It should be noted that the elapsed time calculations were based upon the assumption that the mean surface brightness throughout the scene was constant. However, since points on a scene may vary as much as ±2.5 magnitudes, the observation times for the point of interest may vary from one tenth to ten times the calculated values.

Since the observation time is a function of the intensity of the source, Figure 4-14 is a plot of the numerical distribution of various sources (galaxies, planetary nebulae and emission nebulae) as a function of surface brightness.

4.4.1.2.6 Low-Dispersion Spectrometry. Both slit and slitless spectrometry modes are included in the experiment. In the slit mode of operation, slit spectrography of specific features in large emission nebulae is achieved. The slit spectrograph is capable of 3×10^{-11} m (0.3 Å) spectral resolution and 5×10^{-6} rad (1 arcsec) spatial resolution for extended sources. Slits are also available on command for scanning large nebulae with slit widths of 2.4×10^{-5} rad (5 arcsec) and 8.7×10^{-4} rad (3 arcmin). A series of slits 5×10^{-6} rad (1 arcsec) wide spaced at 2.4×10^{-5} rad (5 arcsec) intervals over 8.7×10^{-4} rad (3 arcmin) range is available for measurement of doppler shifts in galaxies.

In the slitless mode of operation, slitless spectrography in the ultraviolet of selected large planetary nebulae is achieved; i.e., monochromatic imaging with a spectral purity of 1.9×10^{-9} m (19 Å) per 2.9×10^{-4} rad (arcmin) with a spatial resolution better than 5×10^{-6} rad (1 arcsec). For example, if an object 1.45×10^{-3} rad (5 arcmin) in diameter were viewed, complete separation of monochromatic images 9×10^{-9} m (90 Å) apart can be achieved.

The low-dispersion grating is used with any selected slit width for spectrography of the fainter diffuse nebulae, galaxies, and quasars. The low-dispersion grating in the slitless mode is similar to objective prism spectroscopy and is used for searches in selected areas of galaxies, star clusters, and clusters of galaxies. The slitless spectrograph is capable of better than 5×10^{-6} rad (1 arcsec) angular resolution and 2×10^{-11} m (0.2 Å) spectral resolution with 9.4×10^{-9} m (94 Å) per 1.45×10^{-3} rad (5 arcmin) spectral purity. See Figure 5-15 for spectrograph details.

Table 4-7. Exposure Times

Object	Luminance m_V/arcmin^2	Exposure Times					
		3% Photometric Precision			10% Photometric Precision		
		10^{-7} m (1000 Å)	3×10^{-8} m (300 Å)	3×10^{-11} m (0.3 Å)	10^{-7} m (1000 Å)	3×10^{-8} m (300 Å)	3×10^{-11} m (0.3 Å)
Andromeda Galaxy M-31 (NGC 224)							
Continuum	14.3	96 min	13.7 hr.	-	1 min	1.4 hr.	-
Discrete		-	-	37.7 hr.	-	-	3.8 hr.
Crab Nebula (NGC 1952)							
Continuum	13.5	46 min	6.6 hr.	-	4.6 min	40 min	-
Discrete		-	-	18.1 hr.	-	-	1.8 hr.
Bright Diffuse Nebula (NGC 2467)							
Continuum	10.1	1.8 min	15.7 min	-	11 sec	1.6	-
Discrete		-	-	43.1 min	-	-	4.3 min
Planetary Nebulae (NGC 2392)							
Continuum	7.7	0.22 min	1.9 min	-	1.4 sec	10. sec	-
Discrete		-	-	5.06 min	-	-	30. sec

4.4.1.2.7 High-Dispersion Spectroscopy. The spectrograph grating has a grating constant of 150,000 and is theoretically capable of resolving lines 1.2×10^{-12} (0.012 Å) apart. The entrance to the spectrograph (refer to Figure 4-16) is in the focal plane of the telescope (Ritchey-Chretien type). This aperture serves as a field stop when the spectrograph is used in its "nebular" mode; a variety of slits (of different widths) are also available if the system is to be used as a slit spectrograph.

The expanding light beam coming from the entrance aperture goes to a 10.8 cm (7 in.) diameter collimating mirror. This mirror has an oblate spheroid figure (ellipsoid of revolution about the minor axis). Light reflected from the collimator is directed toward the nearly planar diffraction grating (1000 grooves/mm). The grating tilt is variable over a range of 0.157 rad (9°); the angle of incidence varies from 5.2×10^{-2} to 20.8×10^{-2} rad (3° to 12°). The angle between the incident and diffracted beam (first order) is a constant 0.52 rad (30°) for all grating tilt angles. Diffracted light goes to a camera mirror (identical to the collimating mirror) which refocuses the quasi-parallel beam. A flat pick-off mirror, located within the central shadow of the beam, reflects the beam from the camera mirror off to the side where it is recorded by the UV spectrograph camera. This camera may use a TV detector, an image converter/intensifier with film, or film alone.

The spectrograph is designed as a self-contained instrument section which is capable of alignment and test remote from the telescope. Figure 4-16 shows the basic construction and modular approach. The spectrograph design is derived from a compact Czerny-Turner arrangement with a number of significant modifications so that good imagery would be available for a 5.82×10^{-3} (20 arcmin) field of view, without the

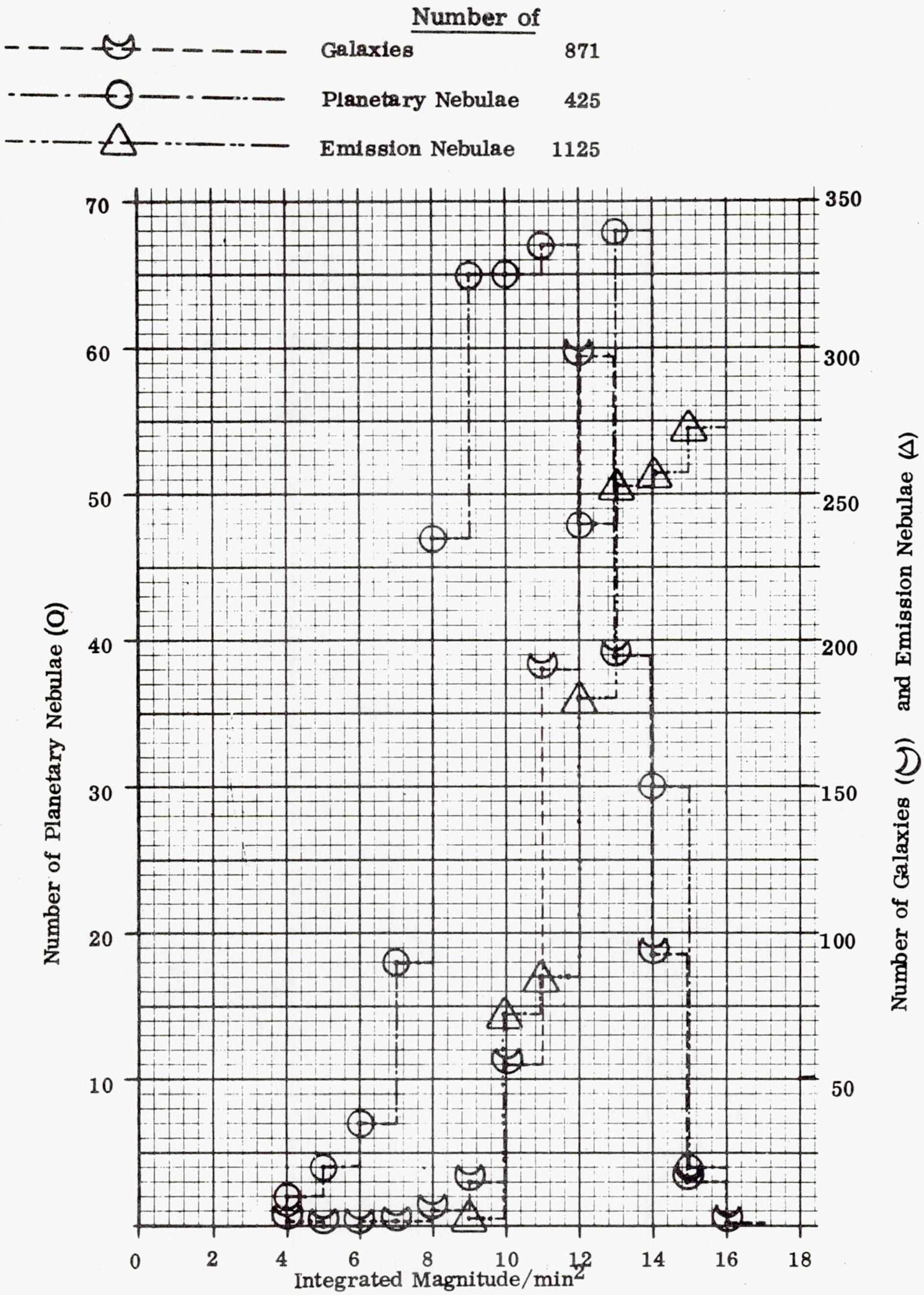


Figure 4-14. Distribution of Objects by Luminance (Surface Brightness)

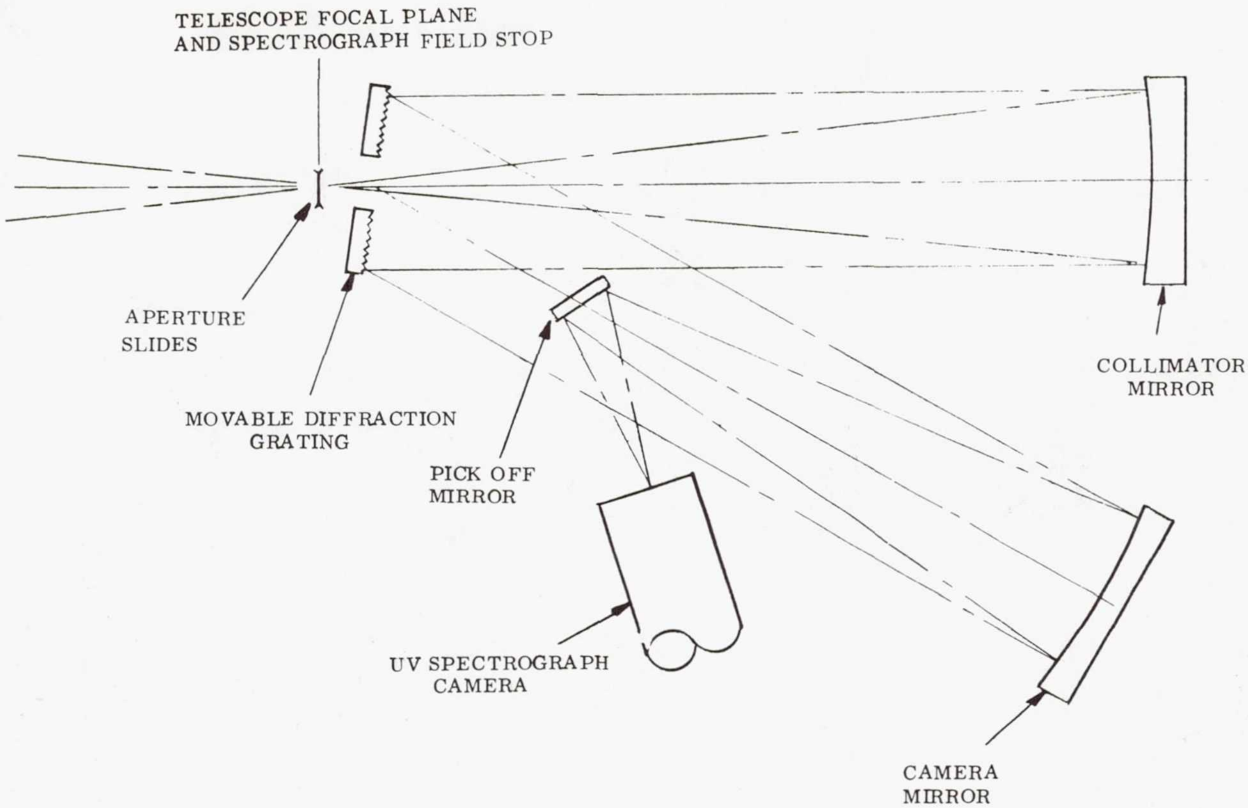


Figure 4-15. Slitless UV Spectrograph

severe stigmatic effect usually present in such a system. A 0.764 M (30 in.) focal length collimator mirror was chosen to keep the spectrograph compact. Since the spectrograph plate scale is to be identical to the Cassegrainian plate scale, the camera mirror is the same focal length as the collimator. The ratio of Cassegrain focal position is seen as 1.89×10^{-3} rad (6.5 arcmin) by the collimator mirror. The telescope is required to view 2.9×10^{-3} rad (10 arcmin) off-axis; thus, the spectrograph collimator is required to view objects 1.89×10^{-2} rad (65 arcmin) off-axis. This enormous field of view rules out using a parabola as a simple collimator (its off-axis aberrations would be unacceptable); instead, it was necessary to use a combination of mirrors, forming a wide-field imaging system. No refractive elements may be used because of the UV requirements of the system.

It was decided to use an all-reflective camera (where an aspheric mirror, tilted to get out of its own way, replaces the refractive correcting plate) as a wide-angle collimator for the spectrograph. In the spectrograph, a grating is ruled on the reflective correcting plate causing all the images in the focal plane to be spread out into spectra (simulating narrow-field objective prism spectrography). The tilted aspheric grating introduces a small astigmatic-like effect into the system, in addition to the uncorrected astigmatism inherent in the camera design. Because it is all-reflective, there is no chromatic aberration to compensate for, so the neutral zone on the aspheric correcting plate may be moved to any desired position (the spherical aberration will still be corrected) to help control astigmatism.

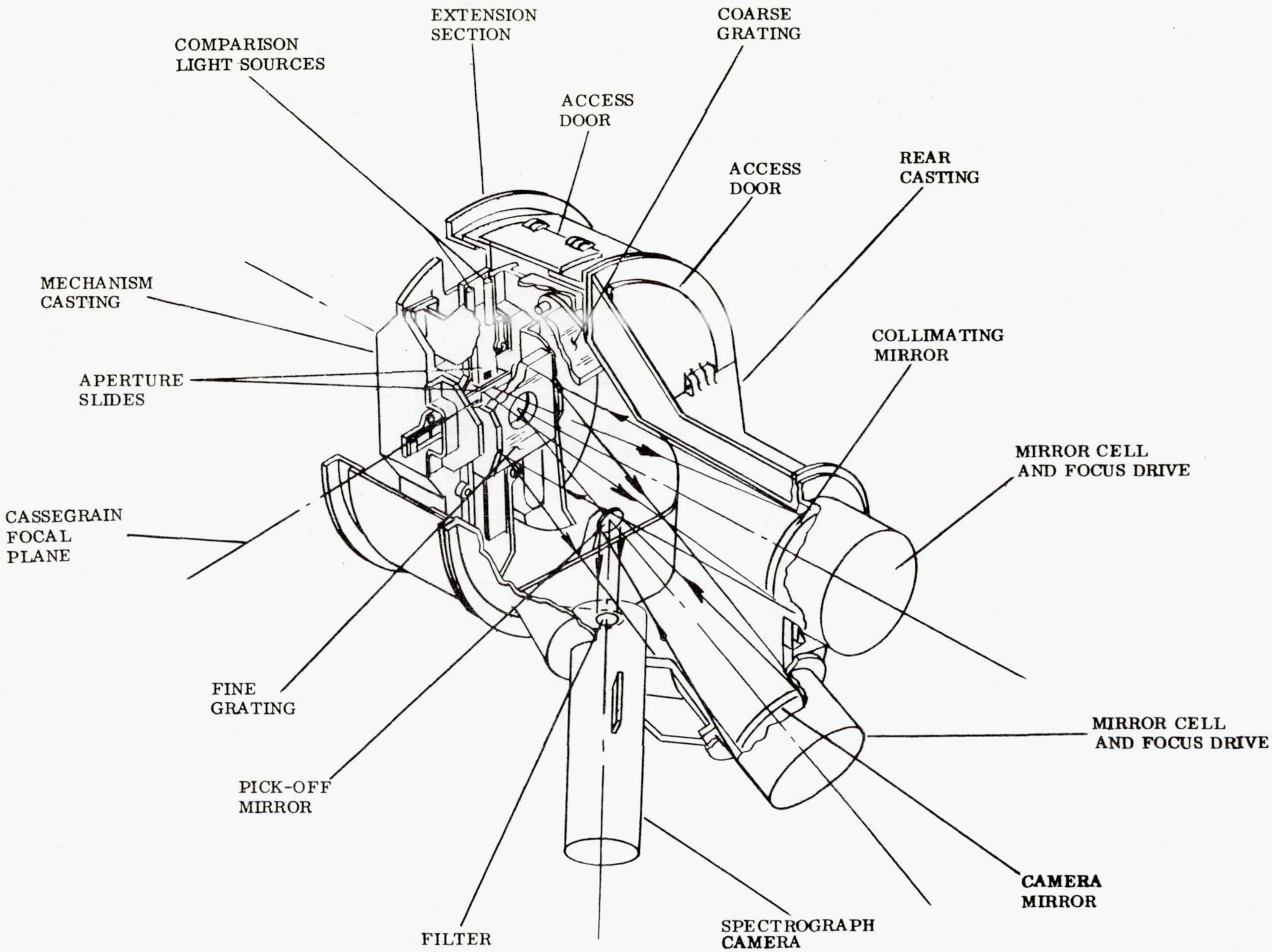


Figure 4-16. Spectrograph Instrument Section

The collimating and camera mirrors are both concave surfaces of revolution about the minor axis (oblate spheroids); the aspheric plate (with the reflecting grating on it) serves as a correcting plate for both camera systems, simultaneously. Both the camera and collimator are used on-axis to minimize off-axis aberrations.

4.4.1.3 Observation/Measurement Program. Table 4-8 shows that the observation times required to record images vary considerably, depending upon such factors as the object under observation, desired signal-to-noise ratio, filter bandwidth, etc. These times can be appreciably shortened by using detectors with image reduction (e.g., a camera equipped with an electronic zoom). For this reason, no attempt has been made to produce an observation time-line. Since the exposure times vary as they do, and time is an important factor, it is felt that the project scientists and the astronaut-astronomer are best qualified to decide which objects are most suitable for the viewing time available. To aid in these decisions, two figures and a table have been prepared. Figure 4-17 is an operational time line. Figure 4-14 is a plot of the number of galaxies, planetary nebulae, and emission nebulae as a function of surface brightness. Table 4-8 lists the required exposure times to achieve 3% photometric precision for objects of surface brightness ranging from 0 m_V/arcmin^2 to 18th m_V/arcmin^2, with 4.85×10^{-6} rad (1 arcsec) resolution.

The large variation in observing times, the detector design, and the thermal stabilization time lead to another conclusion. It has been demonstrated that certain objects of interest can be recorded in five minutes, while some take hours. The telescope, once deployed, does not reach a point of automatic operation for about 20 hours, while the detectors will be designed to be turned on within 5 hours of deployment.

Table 4-8. Observation Times, 3% Photometric Precision, 1 Arcsec Resolution

Surface Brightness m_V/arcmin^2	Surface Brightness Photons-cm^{-2} arcsec^{-2} sec^{-1} Å^{-1}	Required Time - Minutes			
		3×10^{-11} m (0.3 Å (Star)	3×10^{-11} m (0.3 Å) (Nebula)	1×10^{-7} m (1000 Å)	3×10^{-8} m (300 Å)
1	0.120	0.360×10^{1}	0.108×10^{-1}	0.459×10^{-3}	0.437×10^{-2}
2	0.477×10^{-1}	0.905×10^{1}	0.272×10^{-1}	0.115×10^{-2}	0.110×10^{-1}
3	0.190×10^{-1}	0.227×10^{2}	0.682×10^{-1}	0.290×10^{-2}	0.276×10^{-1}
4	0.756×10^{-2}	0.571×10^{2}	0.171	0.728×10^{-2}	0.693×10^{-1}
5	0.301×10^{-2}	0.143×10^{3}	0.431	0.183×10^{-1}	0.174
6	0.120×10^{-2}	0.360×10^{3}	0.108×10^{1}	0.459×10^{-1}	0.437
7	0.477×10^{-3}	0.905×10^{3}	0.272×10^{1}	0.115	0.110×10^{1}
8	0.190×10^{-3}	0.227×10^{4}	0.682×10^{1}	0.290	0.276×10^{1}
9	0.756×10^{-4}	0.571×10^{4}	0.171×10^{2}	0.728	0.693×10^{1}
10	0.301×10^{-4}	0.143×10^{5}	0.431×10^{2}	0.183×10^{1}	0.174×10^{2}
11	0.120×10^{-4}	0.360×10^{5}	0.108×10^{3}	0.459×10^{1}	0.437×10^{2}
12	0.477×10^{-5}	0.905×10^{5}	0.272×10^{3}	0.115×10^{2}	0.110×10^{3}
13	0.190×10^{-5}	0.227×10^{6}	0.682×10^{3}	0.290×10^{2}	0.276×10^{3}
14	0.756×10^{-6}	0.571×10^{6}	0.171×10^{4}	0.728×10^{2}	0.693×10^{3}
15	0.301×10^{-6}	0.143×10^{7}	0.431×10^{4}	0.183×10^{3}	0.174×10^{4}
16	0.120×10^{-6}	0.360×10^{7}	0.108×10^{5}	0.459×10^{3}	0.437×10^{4}
17	0.477×10^{-7}	0.905×10^{7}	0.272×10^{5}	0.115×10^{4}	0.110×10^{5}
18	0.190×10^{-7}	0.227×10^{8}	0.682×10^{5}	0.290×10^{4}	0.276×10^{5}

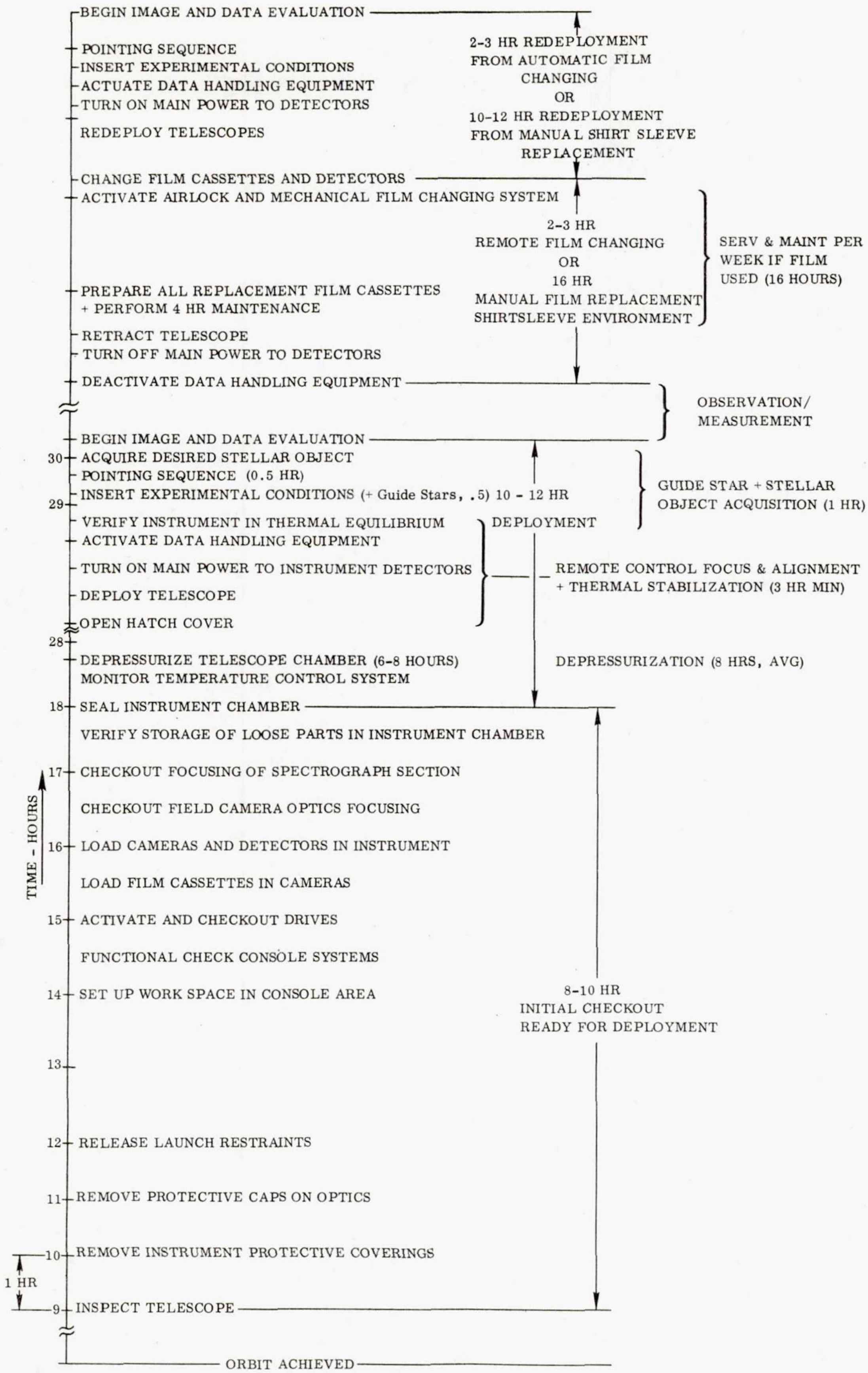


Figure 4-17. Experiment Sequence-Field Photography Mode

Therefore, selected objects of interest requiring short exposure times should be examined first. These will not be appreciably affected by optical shifts caused by thermal changes. Once the 20-hour point after deployment is passed, the long-time observations begin.

Table 4-9 shows typical tasks, time per task, astronaut roles, and preferred work modes for accomplishing experiment preparation, maintenance, and operations.

4.4.1.4 Interface, Support, and Performance Requirements. Interface, support and performance requirements are presented in Table 4-10. The power budget for the system was obtained by a component count based upon previous experience, and using the power consumption figures supplied by the manufacturers. The anticipated power budget is presented in Table 4-11.

It is assumed that one picture will contain approximately 8×10^6 bits. If the data transmission rate is 50 kbs, it will take approximately 2.5 minutes to transmit one picture. There is currently a maximum transmission time of about 10 minutes per orbit, and a maximum of 16 orbits per day, for a maximum transmission time of 160 minutes per day. It is estimated that one picture can be collected in about 20 to 30 minutes. Hence, there will be capability to transmit between 50 and 75 pictures per day. Total transmission time required to send all pictures would be somewhere between 125 and 188 minutes per day.

A second alternative is to increase the telementry rate from 50 kbs to 500 kbs, thus permitting all the collected data to be transmitted to the ground. However, this change in rate would necessitate a threefold increase in spacecraft transmitter power requirements. For Earth orbits, the data transmission rate may go to tens of megabits per second with the advent of the DRSS. (Eventual use of this telescope on interplanetary flights may again cause limited data rates.)

A third alternative is to equip the three primary functions with continuous-feed cameras, each holding a 185-m (600 ft.) reel of film. The film can be exchanged once per month. Up to six data groups per orbit could be recorded, enabling studies of varying stellar objects at an average sampling rate of six images per half orbit. The film can also be expended at rates of one image per second where a rapidly varying stellar object is noted.

To minimize the impact on payload requirements, design considerations will be such as to provide accessibility to critical items whose functions are necessary for precise operation of the entire instrument. Minor replacement will require one astronaut, the replaceable package, a complement of tools, and preferrably a shirtsleeve working environment, although contingency requirements might make IVA or EVA a necessity. Replaceable items such as electronic modules of the plug-in, screw-down, hard-mounted type, roll tracker, OFG, gyros and comparison light source, also hard-mounted, would be used.

Table 4-9. Functions and Allocations for Experiment Sequence

Field Photography Mode	Estimated Time Required (hr)	Possible Roles of Astronaut	Preferred work Mode		
			SS	IVA	EVA
Inspect Telescope - Visual Check	1	O*	1	-	-
Remove Instrument Protective Covering (Fold & Stow)	1	O	1	-	-
Remove Protective Caps on Optics	1	O	1	-	-
Release Launch Restraints	2		1	2	-
Set-Up Work Space in Console Area	1/2-1	O	1	-	-
Functional Check Console Systems	1	O, M*	1	-	-
Activate & Checkout Drives	1/2-1	O	1	-	-
Load Film Cassettes in Cameras**	1/2	O	1	2	-
Load Cameras & Detectors in Instrument	1/2	O	1	2	-
Checkout Field Camera Optics Focusing	1/2	O, M	1	-	-
Checkout Focusing of Spectrograph Section	1/2	O, M	1	-	-
Verify Stowage of Loose Parts in Instr. Chamber	1/2	O	1	-	-
Seal Instrument Chamber	1/2	O	1	-	-
Depressurize Telescope Chamber	6-8	M	-	-	-
Monitor Temp Control System Until Stabilization	-	M	1	-	-
Open Hatch Cover	1/4	O	-	1	-
Deploy Telescope	1/2	O, M	-	-	-
Turn On Main Power to Instrument Detectors	1/4	O	1	-	-

*O = Operator, M = Monitor, V = Experiment Variable
**Assumes film vault in instrument hanger

Table 4-9. Functions and Allocations for Experiment Sequence (Contd)

Field Photography Mode	Estimated Time Required (hr)	Possible Roles of Astro-naut	Preferred work Mode		
			SS	IVA	EVA
Activate Data Handling Equipment	1/4	O	1	-	-
Verify Instrument in Thermal Equilibrium	1/4	M	1	-	-
Insert Experiment Conditions	1/4	O, M	1	-	-
Pointing Sequence	1/2	M, V*	1	-	-
Image & Data Evaluation	1/2	O, M	1	-	-
Deactivate Data Handling Equipment	1/4	O	1	-	-
Turn Off Main Power to Detectors	1/4	O	1	-	-
Retract Telescope	1/2	O, M	1	-	-
Prepare all Film Cassettes	1	O	1	-	-
Activate Airlock & Mechanical Film Changing System	1/4	O, M	1	-	-
Change Film Cassettes and/or Detectors	1/2	O, M	1	2	-
Deploy Telescope	1/2	O, M	1	-	-
Turn On Main Power to Detectors	1/4	O	1	-	-
Activate Data Handling Equipment	1/4	O	1	-	-
Insert Exp. Conditions	1/4	O, M	1	-	-
Pointing Sequence	1/2	M, V	1	-	-
Image & Data Evaluation	1/2	O, M	1	-	-
Develop Film	1/2	O	1	-	-
Film Evaluation	1	O	1	-	-
Packaging & Storage	1/2	O	1	-	-

*O = Operator, M = Monitor, V = Experiment Variable
**Assumes film vault in instrument hanger

Table 4-10. Narrow Field UV Experiment Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Focus and Alignment	b. Guide Stars Acquisition	c. Stellar Object Acquisition and Location	d. Electronic Imaging	e. Backup Film Imaging	f. Low Dispersion Spectrometer	g. High Dispersion Spectroscopy		MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	0.94 m Telescope Guide Star Trackers TV Perf Monitor Electr/Backup Film Camera Low Dispersion Spectrograph High Dispersion Spectrometer	0.94 m Telescope Guide Star Trackers TV Perf Monitor	0.94 m Telescope Guide Star Trackers TV Perf Monitor Electr/Backup Film Camera	0.94 m Telescope Guide Star Trackers TV Perf Monitor Electr/Backup Film Camera	0.94 m Telescope Guide Star Trackers TV Perf Monitor Film Camera Broad Band Filters	0.94 m Telescope Guide Star Trackers TV Perf Monitor Electr/Backup Film Camera	0.94 m Telescope Guide Star Trackers TV Perf Monitor Electr/Backup Film Camera			
Launch Mass, kg										1100
(Weight, lb)										2420†
Logistics Support										
Consumables, kg/180D		-	-	-	11.2	11.2	11.2		33.6	
(lb/180D)					24.6	24.6	24.6		(74)	
Spares, kg/180D										
(lb/180D)										
Crew Support										
Initial Setup, Manhours/180D	8-10								8	10
Periodic Serv. & Maint., Manhours/180D	16 (avg)*								16	16
Depressurization/Cycle	6-8								6	8
Operation, Remote Control, Manhours/Observation Cycle	0.5 to 3	0.5	0.5	0.66 to 4	0.66 to 4, avg. 24, max.**	0.66 to 4	0.66 to 4		4.14	13.5
Electric Power:										
Peak Load, Watts	300	300	300	300	300	300	300		300	300***
Average Load, Watts	266	266	266	266	266	266	266		266	266
Standby Load, Watts	141	141	141	141	141	141	141		141	141
Environmental Control										
Temp. Limits, Stowed, °K	283 to 298	283 to 298	283 to 298	283 to 298	283 to 298	283 to 298	283 to 298		283 to 298	283 to 298
Temp. Range, Ops., °K	289 to 290	289 to 290	289 to 290	289 to 290	289 to 290	289 to 290	289 to 290		289 to 290	289 to 290
Max. Temp. Difference, °K	0.3	0.3	0.3	0.3	0.3	0.3	0.3		0.3	0.3
Relative Humidity, %††	< 40	~ 0	~ 0	~ 0	~ 0	~ 0	~ 0		< 40	~ 0
Atmosphere Limit, N/m^2 (psi)	0 to 10^5 (0-15)	1.33×10^{-4} (<10^{-6} torr)	1.33×10^{-4} (<10^{-6} torr)	1.33×10^{-4} (< 10^{-6} torr)	1.33×10^{-4} (< 10^{-6} torr)	1.33×10^{-4} (<10^{-6} torr)	1.33×10^{-4} (<10^{-6} torr)		1.33×10^{-4} (< 10^{-6} torr)	1.33×10^{-4} (<10^{-6} torr)
Cleanliness Class	10,000	10,000	10,000	10,000	10,000	10,000	10,000		10,000	10,000
Gravity Level, Max. g	$< 10^{-2}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$		$< 10^{-3}$	$< 10^{-3}$
Radiation Sensitivity, millirad/hr	< 1	< 1	< 1	< 1	< 1	< 1	< 1		< 1	< 1
Contamination Sensitivity	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate		Moderate	Avoid (moderate)

*Includes 2 hr for repressurization, 4 hr serv. & maint., 2 hr film cassette changing, 8 hr repressurization
**Occasionally extended to 24 hr with film imaging
***Plus 850W if data handling in telescope system
†Elevator and Service Housing
††Moisture and humidity beyond a few percent should be kept away from shorter-wavelength UV instruments

Table 4-10. Narrow Field UV Experiment Interface, Support, and Performance Requirements (Continued)

INTERFACE OR SUPPORT PARAMETERS \ EXPERIMENT	a. Focus and Alignment	b. Guide Stars Acquisition	c. Stellar Object Acquisition and Location	d. Electronic Imaging	e. Backup Film Imaging	f. Low Dispersion Spectrometer	g. High Dispersion Spectroscopy		MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg			(28 to 70)	(28 to 70)	(28 to 70)	(28 to 70)	(28 to 70)		( )	(28 to 70)
Acceptable Inclination, deg	any	any	any	any	any	any	any		any	any
Desired Altitude, km	463 to 667	463 to 667	463 to 667	463 to 667	463 to 467	463 to 667	463 to 667		-	463 to 667
(n.mi.)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)			(250 to 360)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740		370 to 740	
(n.mi.)	(> 200 to 400)	(> 200 to 400)	(>200 to 400)	(>200 to 400)	(> 200 to 400)	(> 200 to 400)	(>200 to 400)		(> 200 to 400)	
Orientation:										
Observed Object Location										
Observed Object Brightness, mag., m_v	-	> 7	-2.5 to 18	-2.5 to 18	-2.5 to 18	-2.5 to 18	2.5 x18		-2.5 to 18	-2.5 x 18
Observation Field of View, rad	5.8×10^{-3}	5.8×10^{-3}	5.8×10^{-3}	4.6×10^{-3}	4.6×10^{-3}	$(2.4 \text{ to } 87) \times 10^{-5}$	5.8×10^{-3}			
	(20 arcmin)	(20 arcmin)	(20 arcmin)	(17.8 arcmin)	(17.8 arcmin)	5 to 180 arcsec	(20 arcmin)			
Pointing Accuracy, rad	$5 \times 10^{-6}, 1.45 \times 10^{-4}$	$5 \times 10^{-6}, 1.45 \times 10^{-4}$	$5 \times 10^{-6}, 1.45 \times 10^{-4}$	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}		$5 \times 10^{-6}, 1.45 \times 10^{-4}$	5×10^{-6}
(arcsec)	(1, 30*)	(1**, 30*)	(1**,30*)	(<1)	(< 1)	(< 1)	(<1)		(~ 1**,30*)	(<1)
Pointing Stability, rad/obs time	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}		5×10^{-6}	5×10^{-6}
(arcsec/obs time)	(< 1***)	(< 1***)	(<1***)	(<1)	(< 1)	(< 1)	(<1)		(< 1)	(<1)
Slew Rate, max., rad/sec	1.75×10^{-3}	1.75×10^{-3}	1.75×10^{-3}	1.75×10^{-3}	1.75×10^{-3}	1.75×10^{-3}	1.75×10^{-3}		1.75×10^{-3}	1.75×10^{-3}
(arcsec/sec)	(360)	(360)	(360)	(360)	(360)	(360)	(360)		(360)	(360)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}		5×10^{-6}	5×10^{-6}
(arcsec/sec)	(< 1)	(< 1)	(<1)	(<1)	(< 1)	(< 1)	(<1)		(< 1)	(<1)
Pointing Hold Time, sec	2400	Up to 1800	Up to 1800	2400 to 14,400	2400 to 14,400	2400 to 14,400	2400 to 14,400		2400	2400 to 14,400
Data Requirements/Observation Cycle:										
Max. Data Strips/Orbit (if film used)					6	6	6			
Imaging Data										
MTF	>40.0 cycles/mm	>40.0 cycles/mm	>40.0 cycles/mm	>40.0 cycles/mm	~130 cycles/mm >40.0 cycles/mm	>40.0 cycles/mm	>40.0 cycles/mm		>40.0 cycles/mm	>40.0 cycles/mm
Desired Resolution,	5×10^{-6} rad	5×10^{-6} rad	5×10^{-6} rad	5×10^{-6} rad	$<5 \times 10^{-6}$ rad	2×10^{-11} m, 5×10^{-6} rad	1.2×10^{-12} m			1.2×10^{-12} m
(spatial or spectral)	(1 arcsec)	(1 arcsec)	(1 arcsec)	(1 arcsec)	(< 1 arcsec)	(0.2 Å, 1 arcsec)	(0.012 Å)			(0.012 Å)
Equiv. Image Format Size, mm	25.4 x25.4	25.4 x25.4	25.4 x 25.4	25.4 x 25.4	25.4 x25.4	25.4 x25.4	25.4 x 25.4		25.4 x25.4	25.4 x 25.4
Picture Elements/Image	10^6	10^6	10^6	10^6	$\sim 11 \times 10^6$	10^6	‡		$\sim 10^6$	$\sim 10^6$
Images/Data Set	1	1	1	1	1	1	Up to 5		Up to 7	1 to 11
Images/Second	6.95×10^{-5} to 1	1	1	$\sim 6.95 \times 10^{-5}$ to 1	6.95×10^{-5} to 1	6.95×10^{-5} to 1	6.95×10^{-5} to 1		6.95×10^{-5} to 1	6.95×10^{-5} to 1
Photometric Resolution, %, bits	2, 8	2, 8	2, 8	2, 8	2, 8	2, 8	2, 8		2, 8	
Equiv. Analog Data, MHz	11	11	11	11	121	11	1.1×10^{-6} Hz/strip†		11	11
Equiv. Digital Data, bits/image	8×10^6	8×10^6	8×10^6	8×10^6	8.8×10^7	8×10^6	8.8×10^4 per strip		8×10^6	8×10^6
Non-Imaging Data: Command Data, bps	< 100	< 100	< 100	< 100	< 100	< 100	< 100		< 100	< 100
Science/Exp. Data, bps	< 2000*†	< 2000*†	< 2000*†	< 2000*†	< 2000*†	< 2000*†	< 2000*†		< 2000	< 2000
Housekeeping Data, bps	~ 200*†	~ 200*†	~ 200*†	~ 200*†	~ 200*†	~ 200*†	~ 200*†		~ 200	~ 200
Special Requirements:										
Updating Cycle, Years	2	2	2	2	2	2	2		2	2
Mass, kg/yr	9.1	9.1	9.1	27.3	9.1	68	68		240	240
(Weight, lb/yr)	(20)	(20)	(20)	(60)	(60)	(150)	(150)		(480)	(480)
Volume, m^3/yr	0.028	0.028	0.028	0.085	0.085	0.21	0.21		0.68	0.68
(ft^3/yr)	(1)	(1)	(1)	(3)	(3)	(7.5)	(7.5)		(24)	(24)
Data Storage, bits	$>2.5 \times 10^8$	-	-	2.5×10^8	film vault	$>2.5 \times 10^8$	$>2.5 \times 10^8$		2.5×10^8	2.5×10^8
Film Option					35	35	35‡			
Type mm					6.6 (0.22)	6.6 (0.22)	6.6 (0.22)			
Length/Data Strip cm (ft)										

*Max spacecraft body pointing error = 8.7×10^{-3} rad (30 arcsec)

*†If remotely operated in an experiment module

‡Includes basic image, space, and associated reference data readout; six 185-m (600-ft) reels of film per data channel (reel plus film weight = 1.86 kg or 4.1 lb)

**Orientation and star location reference error $<5 \times 10^{-6}$ rad (1 arcsec)

†If spectrometer modified may end up with echelle equiv with 50 strips per frame

***1.7×10^{-6} rad (0.35 arcsec) for pointing and 3.4×10^{-6} rad (0.7 arcsec) for torque disturbances, $A \phi < 5 \times 10^{-6}$ rad (1 arcsec)

‡Electronic tube $\sim 10^3$ per strip; film $\sim 3.3 \times 10^3$

Table 4-11. Power Budget (Average)

Telescope Section		
Mechanisms	10 watts	
Secondary mirror heater	10 watts	
Active temperature control	60 watts	
Television cameras	60 watts	
Fine Guidance Sensor	1 watt	
		141 watts
Control Section		
Circuitry	100 watts	
Displays	25 watts	
		125 watts
Power level with supporting vehicle data handling		266 watts
Data Handling		
Disk memory	800 watts*	
Tape memory	50 watts	
		850 watts
Total Average Power		1,116 watts

*This would be reduced from 800 watts to 300 watts if a disk memory with a capacity of one scene rather than three scenes were used. Total power would then be reduced to approximately 600 watts.

Major replacement would require removal of the rear section of the instrument by two astronauts working for an extended period of time in a shirtsleeve environment to gain access to the spectrograph focus mechanism, grating assembly and slit assembly.

4.4.1.5 Potential Role of Man. An orbital space telescope can employ man for a variety of unique purposes. Man's potential utility can be summarized in terms of his ability to:

a. Enhance system life and increase reliability by performing maintenance and repair and by replenishing and conserving consumable supplies (i.e., power, film). Man's participation also permits simplification of equipment design and special handling of fragile optical components to ensure post-launch integrity.

b. Man can physically change system configurations and perform certain manipulative functions which would be impractical or inefficient to perform in unmanned systems.

c. Man can provide the onboard decision-making capability necessary for the exercise of intelligent control and flexibility, real-time evaluation of data outputs, and adaptation or redirection of experiments on the basis of existing conditions and previous observations.

d. Man will observe and monitor unusual experimental conditions and environmental variables and correlate these with experimental results. Because of his proximity to the equipment, man would also be in an excellent position to make recommendations for modifications to be applied to future operational systems.

e. Man will act as a filter in reducing image and data transmission loads by means of real-time data evaluation before a telemetry link is established.

Man's contribution can perhaps best be explained by considering each of the major functions that the proposed man-machine system can accomplish. For each function, one of three possibilities exists:

a. The system is operated with a man in the loop.

b. The system is required to achieve the same level of operation by purely automatic means, i.e., without a man in the loop.

c. The system cannot achieve the desired levels of performance by any known automatic means feasible at the present state of hardware development; hence a lower level of performance must be accepted.

When comparing categories a and b, it is expected that the nonmanned system can achieve the same level of performance. Hence, the price to be paid for excluding man is a price in additional hardware that must be incorporated to perform the same functions that man would otherwise perform. When comparing categories a and c, the level of performance is not the same, and hence the price that one must pay for excluding man from the loop is in terms of reduced system performance. This reduction may be in either the quality of the collected data or the quantity of data collected. In the following sections, each of the major categories of performance will be evaluated in terms of these three criteria.

4.4.1.5.1 Deployment. There are a number of ways in which man can be useful in the deployment sequence. First of all, if man is not used, it will be necessary to assemble the telescope and all its ancillary parts before launch. This means that the more delicate components such as detectors and cameras will be mounted in place and hence will be subject to strains during the launch period. This in turn implies

either that the parts themselves must be made with greater strength, or that the probability of working after being subjected to high-g forces, vibration, etc., will be lowered. On the other hand, with man being used to deploy the system, these delicate components can be packed separately in shock-proof containers, and can be attached in orbit with a consequent increase in potential system reliability.

A second use of man is to remove protective covers, lens caps, etc, which have been installed before launch to protect the system. If man is not used, it will require various automatic devices, explosive release mechanisms, etc., to perform the same function. Use of such devices reduces, to at least some extent, the potential system reliability and adds to total system weight and complexity.

4.4.1.5.2 Alignment. There is no known method of completely aligning a telescope system in orbit by purely automatic means. Therefore, one can either design an extremely rugged device which has small probability of going out of calibration during launch (the penalty here being an increase in weight, and possibly in complexity, if some auto-adjusting devices are used) or, alternatively, one can use the same telescope design and pay a possible penalty of reduced performance due to improper alignment.

It is conceivable that the telescope could be designed to be aligned from the ground station, but there are two penalties associated with such an approach. First, because the time available for contact per orbit is low, it might be weeks before the telescope was completely aligned. For example, if we assume a communication time of 10 minutes per 90-minute orbit, then it will take at least nine times as long to perform this function by ground control as it would by a man in orbit working directly on the system. This, however, is probably an extremely optimistic estimate, as it assumes that every minute of contact between ground station and orbiting vehicle is usefully employed by the operator doing the alignment. In actuality, due to problems of acquisition and the fact that the communication channel may have noise, the time usage is likely to be less than optimum. In addition, there is the purely human factor of memory and judgment. Alignment is carried out by making a series of adjustments of various lead screws on the different axes, and then visually comparing the effect of this adjustment on the picture image on the TV screen. If a human is working over some continuous time period, he can make a series of adjustments and perceive the effects of these adjustments insofar as they improve the picture quality. However, if he is to make these adjustments over brief periods of time which are separated by intervals of an hour or more, then his perception of improvement or degradation in the picture quality from adjustment to adjustment is necessarily less precise. Hence, he must take a longer time to reach an adjustment level that he feels is satisfactory.

Finally, it should be noted that such a remote alignment will require additional drive motors to replace manually operated controls that would be used by the astronaut in aligning the system directly. Furthermore, there is an additional problem that additional TV cameras must be installed in the system for the sole purpose of alignment, since the entire system must be mounted in its final place before launch. If the

astronaut is used to align the system, however, he can mount the TV camera on the autocollimater during the alignment procedure and then, having finished the procedure, can remove it for use during operation.

If we assume that onboard alignment will take between 12 and 24 hours, and if we further assume that, on the average, only about five or six minutes of each orbit can be used to make adjustments, then the total elapsed time for alignment with a ground controller might be as long as 20 days (for 12 hours in flight) to 40 days (if we assume the astronaut requires 24 hours).

4.4.1.5.3 Spectral-Photometric Calibration. The problem with photometric calibration is almost identical to that of alignment. Recent studies have indicated that an astronaut could calibrate the system in a time period of some nine or ten hours, if he were working directly with the system. Essentially, the procedure is to make densitometer readings of known stars which are exposed under known conditions. Exposure times are chosen on the basis of these readings.

There is no known way of doing this entirely automatically except by means of an extremely elaborate system which would expose the film, automatically develop it, read the densities, and then, on the basis of a preprogrammed check of actual versus computed readings, make assignments of proper experimental conditions. In theory this could be done, but the complexity of equipment would be considerable and much of it would have no other functional use once calibration had been accomplished. Photometric calibration of the electronic imaging devices and film cameras for exposure times by ground observers would require long periods of elapsed time because of the lack of continuous real-time communication with the spacecraft. (However, electronic imaging and the advent of a real-time, wideband data-relay synchronous satellite system may change this conclusion and enable quicker calibration by remotely controlled semi-automated equipment.)

4.4.1.5.4 Operation. In normal operation man can play several different roles. As long as things are operating normally, he will have a relatively small role in direct collection of data (which will be largely automatic) and will concentrate on data analysis. Concomitant with this analysis, he will perform an incidental check on whether the equipment is operating within the desired limits. Temperature changes, for example, can cause changes in focus which may be so small that they would only be noticed by a trained eye observing the collected data. If man is not in the loop, then these changes would not be noted until a considerable amount of data had been collected. By that time performance would, perhaps, have degraded so badly that at least some of the data would be of little or no value. The alternative is to run special calibration checks at periodic intervals. This would have the disadvantage that this is a time-consuming operation during which no data is being collected.

Thus, one of man's most useful and continuous functions is to act as an optimizer of equipment performance and, by monitoring this performance in the data analysis phase, keep the equipment operating at near-peak values.

A second function that man can perform during normal operation is to take advantage of unexpected developments to change the preplanned experiments along more fruitful lines, as a result of the observed data. There is no way that this can conceivably be done by automatic means, so in this function man's capabilities are unique and irreplaceable.

Finally, it should be noted that, by having man present, and using him to change film, far more data can be collected in this mode of operation than could be done in a purely automatic system. Due to the radiation problems an automatic system could not be shielded as well as a man-assisted system wherein the film can be stored remotely from the camera (perhaps in a water-shielded tank) and thus preserved for longer periods than would be possible otherwise. Furthermore, even if adequate shielding could be devised, it would be desirable to develop the film as soon as possible. If an automatic BIMAT system is used, the storage capabilities of the developer within the system are limited to something on the order of two weeks. However, if man is used as a means of replacing the automatic-development sequence, then the developer can be stored under temperature-controlled conditions and utilized only as needed. Thus, the amount of photographic data that can be collected per 120-day interval is four to six times larger than that which could be achieved without his interaction with the system. In addition, the quality of this information will be higher since, acting as a calibrator, he has kept the equipment in optimum condition.

4.4.1.5.5 Data Management. Man will play a vital role in periodically culling the collected data and making decisions, based on his scientific background and experience, as to what part should be transmitted each day. There is, of course, no way in which such decision-making can be mechanized. One alternative for a nonmanned system would be to wait for the periodic deliveries of the collected data. (It is not anticipated that there will be any onboard storage problem.) One picture can be stored on about 3 meters (10 ft) of tape. Hence, one day's collection can be stored on 152 meters (500 ft); and a 610-m (2,000-ft) roll can store all the data collected during 4 days. Hence, about 30 rolls can store enough data for the 120-day period. However, provision needs to be made to protect the film from fogging by radiation. The problem of waiting for this information to be collected at four-month intervals is that with such a system any change in the experimental program, as a function of the data collected, would have to wait for analysis of the amounts collected, so that a change would not be instituted until some six months after the start of the program.

4.4.1.5.6 Maintenance and Repair. Man can make a marked contribution to total system effectiveness by periodic maintenance checks (thus reducing the probability of system failure) or by replacing modules in the event that one of them does fail. It

is difficult to make an accurate assessment of a quantitative value to place upon this contribution since such an assessment depends upon the assumed inherent reliability of the system iteself. In general, of course, man's possible contribution is in inverse proportion to the probability of failure of the system. Clearly, if the system is very reliable, then failure is unlikely, and man can contribute little. However, it should be noted that even if the system is so reliable that there is only one failure per year, on the average, there is still only about a 16 percent probability that the system will complete a two-year mission without failure.

A system that is not manned can only hope to achieve a high level of probability of completing a long mission (more than one year) if there is considerable redundancy. It should be noted, however, that this is not always possible because of necessary design constraints. For example, power supplies (which can be located remotely from the device they are designed to operate) can easily be duplicated. However, in an optical telescope, there is only one focal point, and if a transducer unit is to be located at this point it is not possible to have redundancy. A failure necessarily requires replacement by a similar unit at the identical point. Thus, even a redundantly designed system cannot have as high a potential reliability as can be assured by using man to act as a source of repair or replacement.

4.4.1.5.7 Retrofit. Closely allied to, but distinct from, the problem of maintenance is the use of man to retrofit the system during a long mission. In maintenance, it is assumed that failure of an element will result in replacement of that element by an identical or at least very similar element. In the case of retrofit, however, an element might be replaced even if it had not failed. The reason might be twofold. First, in a long mission, lasting more than a year, new developments in the state of the art might result in the procuring of a device which could give considerable better results than those achievable by the present instrumentation. Thus, it would be useful to maximize the system performance by making such a replacement even though the present unit were working satisfactorily. Second, a change in the experimental plan, as a function of new discoveries, might make it useful to replace one type of unit with a different type (i.e., a camera with a vidicon, for instance, or vice versa) and thus maximize the type of data that is being collected.

It is obvious that the first type of retrofit cannot be achieved at all without man's intervention. In an unmanned system the second type of retrofit (replacement of one type of unit by another) could only be achieved by preplanning which incorporates every alternate type of instrument that might someday be useful during the mission. This latter course is clearly uneconomical in terms of system weight and complexity and would, moreover, make for extraordinarily difficult design problems, since the telescope instrument pallet would now have to be designed so that any given instrument could be switched automatically into position if, and when, a need for it became evident.

4.4.1.6 Available Background Data

a. Manned Astronomical Space Telescope, Volume II, Technical Report, Contract No. NAS 5-11088, July 1969, Kollsman Instrument Corporation.

b. Orbital Support Facility (OASF) Study, Report No. DAC-5813, Volume III, Douglas Missiles and Space Systems Division, McDonnell-Douglas Corporation.

4.4.2 WIDE-FIELD UV TELESCOPE SURVEY EXPERIMENTS

4.4.2.1 Scientific or Technical Objectives. Wide-field UV Telescope survey experiment objectives are:

a. Imaging of objective-grating stellar spectra in the 9×10^{-8} to 2×10^{-7} m (900 to 2000 Å) wavelength region, with a wavelength resolution of 2×10^{-10}m (2Å) or better.

b. Moderate-resolution far-ultraviolet direct-imaging of selected objects and Milky Way fields.

c. Development of instrument technology and in-flight procedures of potential value in the efficient wide-area surveys.

d. Extension of photographic spectroscopy into the region of the Lyman series of atomic and molecular hydrogen (primary goal of this FPE).

The entire sky should be mapped in the ultraviolet, with special emphasis on known strong ultraviolet sources. This survey would provide a basis for selecting areas for detailed studies by larger, more sophisticated instruments.

4.4.2.2 Description. Wide-field UV experiments will make use of the 0.3-m telescope described in Section 4.2.2, together with sensing, image-intensifier, electronic and backup film imaging equipment, and spectrometer described later in this section. Instruments discussed are derived from current technology; performance of sensors is expected to improve during the life of the telescope to make full use of inherent telescope resolution.

4.4.2.2.1 Focus, Alignment, and Calibration. A selected star field will be utilized for adjustment of image converter, intensifier and/or electronic imaging stages for optimum coupling with the 0.3-meter wide-field telescope. Backup film images also may be obtained against the known UV star pattern to keep track of the condition of the equipment and to provide a basis for determining appropriate exposure times for observations. Photometric calibration procedures are similar to those of the narrow-field UV telescope.

4.4.2.2.2 Observation Area Acquisition. Either supporting-vehicle star-tracker aid or a telescope-mounted coaxial star tracker will be used to guide the 0.3-meter

telescope to the pointing and stabilization performance given in Table 4-13. The method utilized is dependent upon whether the telescope is body-mounted to a free-flying vehicle or gimballed.

4.4.2.2.3 Electronically Augmented Imaging. In Figure 4-18, a camera for direct photography (or objective-grating spectra) is shown. It may be coupled to the wide-field UV telescope and used for a direct image without a grating. The f/1.5 camera uses a MgF_2 corrector plate. A photocathode is located on the focal surface. Photoelectrons are accelerated and magnetically focused onto a phosphor-fiber optics surface. To avoid severe loss of resolution, the curvature of this surface will partially correct for distortions of the electric field introduced by the curved photocathode. The second stage can be a standard (WL 30677) image tube or a vidicon tube, each coupled to the first stage by fiber optics.

From this design one can generate a family of astronomical instruments with various optical focal ratios. The expected resolution of the system is about 25 line pairs/mm or better with 6 μm fiber optics. Development efforts predict 40 line pairs/mm will be attainable. The instrument as depicted in Figure 4-18 can image a 0.175 rad (10°) field on a 25 cm square exit window. With 40 line pairs/mm resolution at the window, this results in 1.7×10^{-4} rad (35 arcsec) angular resolution. A larger instrument can place the same field on a 100 cm square window, yielding 4.4×10^{-5} rad (9 arcsec) resolution if 40 line pairs/mm is attained. The gain of the camera depends on wavelength. Use of an opaque photocathode (e.g., about 40% efficiency for CsI at $\lambda = 1500$) and of a phosphor as a photon producer yields an expected photon gain of about 2500 (output photons per incident photon). Of course, the speed and/or limiting magnitude is determined largely by the focal ratio of the optics and the demagnification factor of the second stage used.

Both versions (vidicon or WL 30677) are easy to use. Normal orthochromatic II_a D film is used with WL 30677. An SEC vidicon tube with a 25.4×25.4 mm usable imaging surface and 40 line pairs/mm is currently available; a 100×100 mm usable imaging surface is planned for development. The 25.4×25.4 mm surface results in 10^6 picture elements and the 100×100 mm surface results in 1.6×10^7 picture elements.

The instrument will be capable of filter-band photometry in the range 2000Å to 3000Å. However, the instrument described above is not suitable for very wide passbands because all available materials for the corrector plate have indexes of refraction which change very rapidly with wavelength in the UV and introduce optical aberrations. Therefore, if broad bandpass is desired, a different optical approach would be preferred. Currently, subtraction photometry may be employed to extend the shorter wavelength limit to 1000Å. However, future development in transmission filters may allow the instrument to be used in this range without resorting to techniques of this type. Further improvements are expected, with alternative methods and updated instruments which can be substituted for the intensifier and imaging equipment at the focus of the telescope.

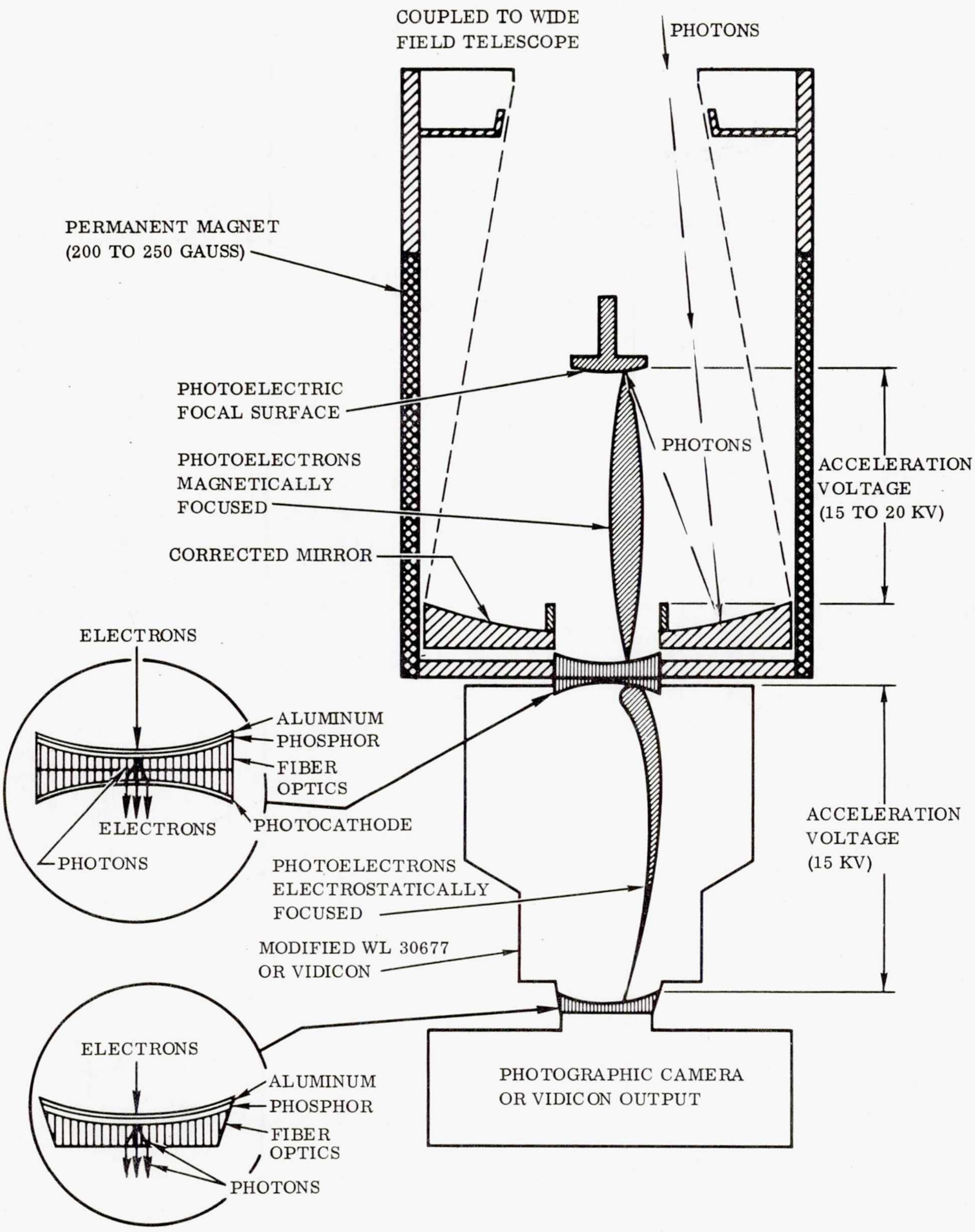


Figure 4-18. UV Image Converter/Image Intensifier Combination

Objective grating spectroscopy is currently feasible in the range 1000Å-3000Å with this instrument by automatic insertion of a grating in the optical path at or near the corrector plate.

4.4.2.2.4 Film Imaging. Film may be coupled to the fiber optics of the first or second stage as necessary to image the UV sources of interest. Methods are expected to be developed where the observer can readily switch from all-electronic imaging to electronic intensification and film recording as necessary. Film format is expected to be 150 mm as indicated in Section 4.2.2.

4.4.2.2.5 Objective Grating Spectrometry. Table 4-12 shows characteristics of a better resolution spectral measurement capability than the option discussed in Section 4.4.2.2.3. The spectral measurement is accomplished by means of an objective grating which is ruled on one of the corrector plates of the band selector (grating turret). The correcting plate has a grating frequency of 110 lines per mm, resulting in a 2×10^{-10}m (2 Å) resolution and 10^{-8}m (100 Å) mm dispersion.

4.4.2.3 Observation/Measurement Program. The following observation measurement cycle is recommended for use with the wide-field UV telescope:

Ops	Task	Time (hr/cycle)	Number of Cycles
S/U	Telescope/Instrument Setup	4	1
O/M	Observation/Measurement		
a	Alignment & Calibration	1	1 per star field
b	Guide or Reference Stars Acquisition & Stabilizations	0.1	1 per star field
c	Clear Picture Star Field Electronic Imaging	0.1 to 0.66	1 per star field
d	Corrector Plate Rotation to objective grating side	0.1	1 per star field
e	Spectrographic Observation with Electronic Imaging	0.1 to 0.66	1 per star field
f	Optional Backup Film Imaging	0.2 to 4	1 per star field
g	Total for Electronic Imaging Observation Cycle	1.3 to 2.52	1 per stellar object
h	Total for Backup Film Imaging Cycle	1.6 to 4.86	1 per source

Table 4-12. UV Spectrometer Characteristics

Wavelength	
Short	9×10^{-8} m (900 Å)
Long	4.3×10^{-7} m (4,300 Å)
Resolution	2×10^{-10} m at 1.2×10^{-7} m (2Å at 1,200Å)
Incident Radiation	
f/No. limitation	5
Spatial resolution	1.45×10^{-5} to 2.4×10^{-5} rad (3 to 5 arcsec)
Main Grating	
Type	Aspheric
Size	300 mm
Ruling frequency	110 lines/mm
Dispersion	10^{-8} m (100Å)/mm at 1.2×10^{-7} m (1,200Å)
Angle of diffraction range	-11.4° to -13.5°
Spectral order	1
Recorder Characteristics	Electronic imaging camera or alternate
Type	Phosphor-augmented camera
Aperture	150 mm
Remote change cycle time	1 sec
Backup Film Camera	
Film type limitations	Roll film
Exposure per magazine load	144
Power consumption during cycle change	5 W
Power consumption during calibration	10 W
Weight of Camera	15 kg (33 lb)

Ops	Task	Time (hr/cycle)	Number of Cycles
i	Repeat a through c	1.3 to 2.52	1 per next source
M	Maintenance		
S_p	Periodic Servicing	4 hours	1 per week
M_{us}	Unscheduled Maintenance	2 hours	1 per year

4.4.2.4 Interface, Support and Performance Requirements. Table 4-13 shows the wide-field UV telescope experiment interface, support and performance requirements.

4.4.2.5 Potential Role of Man. There are three possible roles associated with the functions of the astronaut:

a. As an operator, the astronaut is directly involved as a sensor, processor, actuator and/or manipulator.

b. As a monitor, he is not directly involved in the performance of a functional element, but serves as a monitor to provide additional evaluation backup and override capability for automated or ground-controlled functions.

c. As an experiment variable, the astronaut is used as an independent variable (i.e., in comparisons of remote vs. proximal system performance), as a dependent variable (i.e., in comparison of human performance or of disturbances created with alternative equipment configurations or procedures), or as a stimulus source (i.e., as a creator of various levels of disturbances for use in evaluating tracking stability).

Prior to the gathering of experimental data, the astronaut will be required to perform a specified routine changing the instrument from a launch configuration to an operational configuration.

Man can be used in star field identification, manual pointing of the ultraviolet instruments, and in film retrieval. In each of these areas, man's contribution also will be evaluated to determine his potential usefulness in future endeavors. However, to reduce the manpower required, the basic observation program will be conducted automatically, except for special circumstances or events, after initiation by an astronaut.

4.4.2.6 Available Background Data.

a. Orbital Astronomy Support Facility (OSAF) Study. NAS8-21023, McDonnell-Douglas Corporation, Huntington Beach, California.

b. Far-Ultraviolet Astronomical Observations with an All-Reflecting Telescope, proposal to NASA from Northwestern University.

4.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

Table 4-14 combines the requirements of the narrow-field telescope and of the wide-field telescope and their associated experiments. The combined requirements reflect the support required of the experiment facility carrier vehicle, associated logistics vehicles, and ground-based astronomy control centers. These experiments differ from the other astronomy experiments in that maximum effectiveness is achievable by film, although restricted wide-field work may be accomplished by electronic imaging. A series of improved instruments are expected to be exchanged for the initial set of instruments at updating intervals of 1 to 2 years.

4.6 POTENTIAL MODE OF OPERATION

Contamination sensitivity of the UV telescopes indicates that the two telescopes and their associated instruments should be installed in a free-flying vehicle to obtain maximum freedom from spectral interference, brightness background, and contamination deposition effects. However, both telescopes are more effective with film than with electronic imaging in terms of resolution. Film would be used for wide-field detailed (high resolution) survey work, requiring frequent loading of film cassettes.

Furthermore, both telescopes were designed for a gimballed mounting to work from a Space Station. Space performance of the narrow-field telescope is also being evaluated to obtain a basis for a one-meter telescope to be used on interplanetary flights. Preferably the telescopes should be installed on a manned space vehicle but the spacecraft or Space Station contamination levels need to be decreased sufficiently not to impede UV telescope operations.

The application of this experiment package to each of the proposed mission modes is as follows:

Mission A - Limited On-Orbit Stay Time With Space Shuttle. Either one or both of the experiments in this FPE would be useful with the Shuttle-sortie mission. Of course, increased time on-orbit would greatly enhance the amount of scientific data, but much benefit could be derived even in missions as short as five days. It would be hoped that missions this short, however, could be repeated several times.

Mission B - Extended Orbit Stay Time Revisited By a Shuttle. This mission is very attractive for the Intermediate-Size UV Telescopes when used with the RAM. The telescope/spacecraft package could be launched by the Shuttle, deployed, checked out, and left for extended observations. Revisits by a Shuttle in approximately one-year intervals would provide for maintenance, repair, and updating. After several years in orbit the entire package could be returned to earth for refurbishment if desired.

Mission C - Extended Mission In Conjunction With Space Station. This mission mode adds the possibility of more frequent maintenance, and real-time control from

personnel in the Space Station. Even though this is not considered essential for successful scientific results, it would certainly be a benefit. If operated attached, which appears possible, the contamination levels must be carefully controlled.

4.7 POTENTIAL ROLE OF MAN

An orbital space telescope can gainfully employ man for a variety of unique purposes. His presence significantly enhances the life and reliability of the system. The reliability of the telescope for a manned mission with spares is calculated to be 96% for one year and 91% for two years. By comparison, the unmanned system with redundant circuitry added has a reliability of 90% for one year and 81% for two years. Thus, man is available for repair and/or replacement of parts as well as for updating equipment with newly supplied items such as improved cameras, special filters and new film. In addition, his ability to unlock, inspect, align and prepare for deployment eliminates the need for many complex mechanisms which would otherwise be required for caging systems in order to survive launch. Thus, the telescope may be kept efficiently operating on a long term basis. Man's presence and monitoring provides additional benefits in that phenomena not yet observed, or unexpected phenomena, may be discovered. Thus, an onboard decision-making capability is provided for intelligent control and flexibility of observation for real-time data evaluation of the data outputs. In addition, man can physically change system configurations by accomplishing tasks which are impractical on a remote, unmanned basis.

Repair and maintenance of the telescopes is performed in a shirtsleeve environment. The concept not only permits replacement of detectors and filters, but also the capability of removal of the spectrograph for repair or replacement with another instrument.

To summarize man's role, man is useful for optimizing:

- Data collection
- Data quality
- Experiment useful life
- Useful observation time
- Experiment flexibility

One of the primary reasons that justifies the presence of man on long-duration missions is his capability for increasing system reliability. This is accomplished through a program of scheduled maintenance and provision for contingency repairs.

The astronaut will be required to perform certain specific functions which will enable the instrument to perform properly and carry out scientific experimental objectives.

Most of his work would be performed in a shirtsleeve environment dressed in coveralls and booties unencumbered by life support equipment. The astronaut will also have the capability of working inside a telescope-servicing chamber in the vacuum of space (to avoid long pressurization and depressurization cycles for the equipment) by utilizing an umbilical-type life support system and a modified spacesuit (IVA). In this way the astronaut will be safeguarded against floating off into space as would be the case if the tether arrangement malfunctioned in the EVA mode. In addition, the chamber configuration will provide the handholds and footholds necessary for the astronaut to perform maintenance and repair functions.

The astronaut, having completed an intensive, highly specialized preflight training, will have the capability of performing unscheduled maintenance. Based on the fact that performance of manual tasks in an EVA mode is at least twice as difficult as in a shirtsleeve mode, unscheduled maintenance will be performed in a pressurized environment with an emergency provision for a "save the experiment" contingency in the EVA mode. Specifically, due to a change in experiment format or breakthroughs in state-of-the-art technology, the astronaut may be requested to change cameras in the field photography section of the instrument, replace camera filters, or replace the spectrograph. These are relatively simple tasks which may be handled by one astronaut using keying techniques and removable handles on the replacement packages.

Repair in space can be quite a formidable task requiring much peripheral equipment to complete even the most basic of repairs. Thus, replacement rather than repair will be the philosophy adopted in the event of a failure in any portion of highly reliable systems.

The third and most critical category of repair is the mission-contingency fix in which the astronaut is placed in the mechanical instrument system loop and uses mechanical means of overriding failures in mechanical systems which would impair the usefulness of the experiment.

4.8 SCHEDULES

Table 4-15 presents predicted schedules for development and qualification of the two manned space system telescopes and their associated instruments. Estimates are based on state of art.

4.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

The launch area should have a 10,000-class cleanliness optics laboratory room big enough to accommodate the deployed configurations of the two UV telescopes and their associated gimbal, elevator, and servicing housing assemblies at the same time. A second UV instrument laboratory should adjoin the assembly test laboratory to enable bench test of each of the experiment instruments as well as to enable coupling of

Table 4-13. Wide Field UV Telescope Survey Experiment Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Focus and Alignment	b. Observation Area Acquis. & Loc.	c. Electronic Imaging	d. Backup Film Imaging	e. Spectrometry				MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	Wide Field UV Telescope Objective Gratings Guide Star Trackers Electronic/ Backup Film Cameras	Wide Field UV Telescope Guide Star Trackers Electronic Imaging (Monitor Camera)	Wide Field UV Telescope Electronic UV Converter/ Intensifier/ Electronic Camera Guide Star Trackers	Wide Field UV Telescope Optional UV Converter/ Intensifier/ Film Camera Optional Direct Film Camera	Wide Field UV Telescope Rotable Objective Grating Optional UV Converter/ Intensifier/ Electronic Camera or Film Camera					
Launch Mass, kg (Weight, lb)									430 (950)	430 (950)
Logistics Support										
Consumables, kg/180D (lb/180D)	—	—	—	16.8 (37)	16.8 (37)				33.6 (74)	33.6 (74)
Spares, kg/180D (lb/180D)										
Crew Support										
Initial Setup, Manhours/180D	4	—	—	—	—				4	4
Periodic Serv. & Maint., Manhours/180D	4	—	—	—	—				4	4
Operation, Remote Control, Manhours/Observation Cycle	1	0.1	0.1 to 0.66	0.2 to 4	0.1 to 4				1.3 to 2.52	1.6 to 4.88
Electric Power:										
Peak Load, Watts	325*	125	325*	325*	325*				125 to 325	325*
Average Load, Watts	320	120	320	320	320				120 to 320	320
Standby Load, Watts	120	120	120	120	120				120	120
Environmental Control										
Desired Vehicle Heat Sink Temp, °K										
Temp. Limits, Stowed, °K	263 to 298	263 to 298	263 to 298	263 to 298	263 to 298				263 to 298	263 to 298
Temp. Range, Ops., °K	290 to 291	290 to 291	290 to 291	290 to 291	290 to 291				290 to 291	290 to 291
Max. Temp. Difference, °K	0.5	0.5	0.5	0.5	0.5				0.5	0.5
Relative Humidity, %	<40	~0	~0	~0	~0				< 40	~0
Atmosphere Limit, N/m^2 torr	0 to 10^5 (0-15) psi	1.33×10^{-4} (10^{-6} torr)	1.33×10^{-4} (10^{-6} torr)**	1.33×10^{-4} ($<10^{-6}$ torr)**	1.33×10^{-4} ($<10^{-6}$ torr)**				1.33×10^{-4} ($<10^{-6}$ torr)	1.33×10^{-4} ($<10^{-7}$ torr)
Cleanliness Class	10,000	10,000	10,000	10,000	10,000				10,000	10,000
Gravity Level, Max. g	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$	$<10^{-3}$				$<10^{-3}$	$<10^{-3}$
Radiation Sensitivity, millirad/hr	<1	<1	<1	<1	<1				<1	<1
Contamination Sensitivity	Moderate	Moderate	Moderate	Moderate	Severe					Avoid contamination

*Optional use of image converter/intensifier adds 200W
**10^{-7} torr preferred

Table 4-13. Wide Field UV Telescope Survey Experiment Interface, Support, and Performance Requirements, (Contd)

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Focus and Alignment	b. Observation Area Acquis. & Loc.	c. Electronic Imaging	d. Backup Film Imaging	e. Spectrometry				MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	28 to 70	28 to 70	28 to 70	28 to 70	28 to 70				—	28 to 70
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0				55 to 0	—
Desired Altitude, km	463 to 667	463 to 667	463 to 667	463 to 667	463 to 667				—	463 to 667
(n.mi.)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)	(250 to 360)					(250 to 360)
Acceptable Altitude, km	370 to 740	370 to 740	370 to 740	370 to 740	370 to 740				370 to 740	—
(n.mi.)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)	(200 to 400)				(200 to 400)	
Orientation:										
Observed Object Location	>π/2 rad (90°) from earth center of sun	>π/2 rad (90°) from earth center of sun	>π/2 rad (90°) from earth center of sun	>π/2 rad (90°) from earth center of sun	>π/2 rad (90°) from earth center of sun				>π/2 rad (90°) from earth center of sun	>π/2 rad (90°) from earth center of sun
Observed Object Brightness, mag., m_v	-2.5 to 18	-2.5 to 18	-2.5 to 18	-2.5 to 18	-2.5 to 18				-2.5 to 18	-2.5 to 18
Observation Field of View	0.174, 3×10^{-4} rad (10°, 3 arcmin)	0.174, 3×10^{-4} rad (10°, 3 arcmin)	0.174, 3×10^{-4} rad (10°, 3 arcmin)	0.174, 3×10^{-4} rad 10°, 3 arcmin)	0.174, 3×10^{-4} rad (10°, 3 arcmin)				0.174, 3×10^{-4} rad (10°, 3 arcmin)	0.174, 3×10^{-4} rad (10°, 3 arcmin)
Pointing Accuracy, rad	2.4×10^{-5}	2.4×10^{-5}, 5×10^{-6}	2.4×10^{-5}, 5×10^{-6}	2.4×10^{-5}, 5×10^{-6}	2.4×10^{-5}				2.4×10^{-5}	5×10^{-6}
(arcsec)	(5)	(5, 1)	(5, 1)	(5, 1)	(5)				(5)	(1)
Pointing Stability, rad/obs period and Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}	5×10^{-6}	2.4×10^{-6}	2.4×10^{-6}				5×10^{-6}	2.4×10^{-6}
(arcsec/sec)	(1)	(1)	(1)	(0.5)	(0.5)				(1)	(0.5)
Slew Rate, max., rad/sec	1.74×10^{-3}	1.74×10^{-3}	1.74×10^{-3}	1.74×10^{-3}	1.74×10^{-3}				1.74×10^{-3}	1.74×10^{-3}
(arcsec/sec)	(360)	(360)	(360)	(360)	(360)				(360)	(360)
Pointing Hold Time, sec	Up to 3600	360	360 to 2400	360 to 14,400	360 to 14,400				360 to 2400	260 to 14,400
Data Requirements/Observation Cycle:										
Data Sets per Orbit	1	1	1	1	1				1	1
Imaging Data										
Desired Resolution, radian (spatial or spectral)	1.45×10^{-5} rad (3 arcsec)*	1.45×10^{-5} (3)*	1.45×10^{-5} (3)*	1.1×10^{-5} (2.3)*	1.45×10^{-5}, 2×10^{-10} m (3 arcsec)*, (2 Å)				1.45×10^{-5} (3 arcsec)*	1.1×10^{-5}, 2×10^{-10} m (2.3 arcsec), (2 Å)
Equiv. Image Format Size, mm	25.4×25.4 (100×100)*	25.4×25.4	25.4×25.4 (100×100)*	(120×120), *** (100×100)*	120×120, *** (100×100)*				120×120, 100×100, 25.4×25.4	100×100, 120×120
Picture Elements/Image	10^6, to 1.6×10^7	10^6	10^6 to 1.6×10^7	1×10^9, 3×10^8	10^6 to 1.6×10^7				10^6 to 1.6×10^7	3×10^8, (10^9)
Images/Data Set	1		1	1	1					
Images/Second	6.95×10^{-5} to 0.1	1	4×10^{-4} to 0.1	6.95×10^{-5} to 1	6.95×10^{-5} to 1				4×10^{-4} to 0.1	6.95×10^{-5} to 1
Photometric Resolution, %, bits	1, 7 (log)	1, 7 (log)	1, 7 (log)	1, 7 (log)	1, 7 (log)				1, 7 (log)	1, 7 (log)
Equiv. Analog Data, MHz (Hz)	11, (1.87×10^8)	11	11, (1.87×10^8)	$(1.1\times10^{10}, 3.3\times10^9)$	11, (1.87×10^8)				11**	(1.87×10^8)*
Equiv. Digital Data, bits/image	7×10^6; (1.12×10^8)	(7×10^6)	7×10^6; (1.12×10^8)	7×10^9, 2.1×10^9)	7×10^6, 1.12×10^8				7×10^6**	1.12×10^8*
Non-Imaging Data: Command Data, bps	200	200	200	200	200				200	200
Science/Exp. Data, bps	1000	1000	1000	1000	1000				1000	1000
Housekeeping Data, bps	100	100	100	100	100				100	100
Special Requirements:										
Updating Cycle, Years	1	1	1	1	1				1	1
Mass, kg/yr (Weight, lb/yr)	20 (44)	11 (22)	20 (44)	11(22)	9.1 (20)				68 (152)	68 (152)
Volume, m^3/yr (ft^3/yr)	0.056 (2)	0.028 (1)	0.056(2)	0.056 (2)	0.028 (1)				0.226 (8)	0.226 (8)
Film Option:										
Type				150 mm***	150 mm***					
Length (orbit cm (in.)				15 (5.9)	15 (5.9)					

** If a limited part of the 0.174 rad (10°) wide field is imaged.

*** 150 x 150 mm frames of film, 180 frames per reel, 340 g (0.75 lb.)/reel

* Initial electronic imaging will be capable only of a resolution of about 4.36×10^{-5} rad (9 arcsec), improving to about 1.45×10^{-5} rad (3 arcsec).

Table 4-14. FPE Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	4.4.2 Narrow Field UV Telescope Experiments	4.4.2 Wide Field Telescope Experiments							ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:										
Launch Mass, kg (Weight, lb)	1100 (2420) + Elevator and Service housing	431 (950) + Elevator and Service housing								1531 (3370) + 2 Elevator and Service housing assemblies
Logistics Support										
Consumables, kg/180D (lb/180D)	33.6 (74.0)	33.6 (74.0)								67.2 (148)
Spares, kg/180D (lb/180D)										
Crew Support										
Initial Setup, Manhours/180D	10	4								14
Periodic Serv. & Maint., Manhours/Week	16	4								20
Depressurization/Cycle	8	8, if used								16
Operation, Remote Control, Manhours/Observation Cycle	13.5	1.6 to 4.86								18.36
Electric Power:										
Peak Load, Watts (134 watts counting)	300*	325								625*
Average Load, Watts	266	320								586
Standby Load, Watts	141	120								261
Environmental Control										
Temp. Limits, Stowed, °K	283 to 298	283 to 298								283 to 298
Temp. Range, Ops., °K	289 to 290	290 to 291								289 to 291
Max. Temp. Difference, °K	0.3	0.5								0.3, 0.5
Relative Humidity, %	~ 0	~0								~0
Atmosphere Limit, N/m^2 torr	$0-10^5$ $< 10^{-6}$, $< 10^{-7}$ pref	$< 10^{-6}$, 10^{-7} torr pref							$< 10^{-6}$	$< 10^{-7}$
Cleanliness Class	10,000	10,000								10,000
Gravity Level, Max. g	$< 10^{-3}$	$< 10^{-3}$								$< 10^{-3}$
Radiation Sensitivity, millirad/hr	< 1	< 1								< 1
Contamination Sensitivity	Avoid (moderate)	Avoid (moderate)								Avoid (moderate)

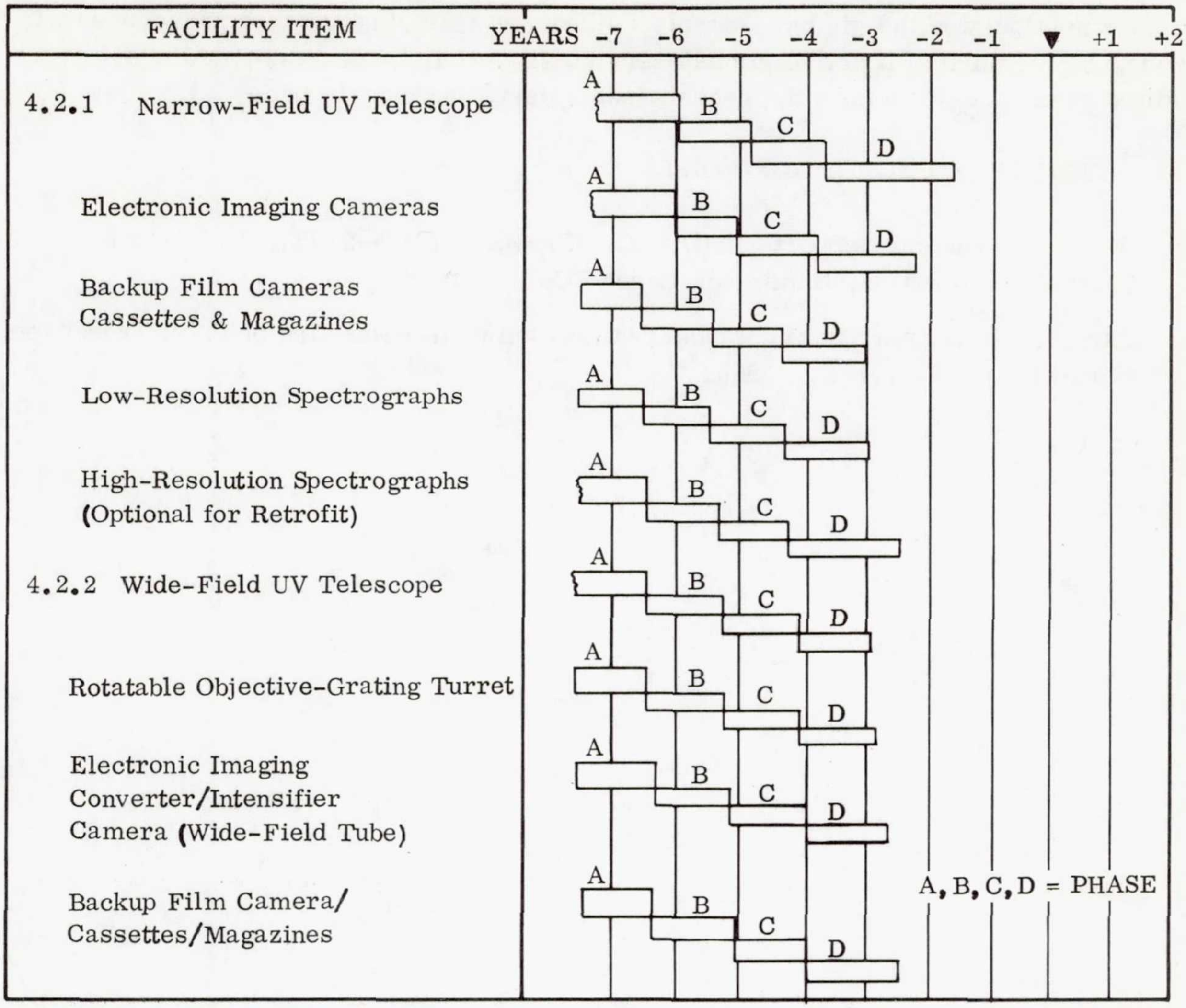
*If data handling in telescope system (+850W)

Table 4-14. FPE Interface, Support, and Performance Requirements, (Contd)

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	4.4.1 Narrow Field UV Telescope Experiments	4.4.2 Wide Field Telescope Experiments							ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	28 to 70	28 to 70								28 to 70
Acceptable Inclination, deg	any	any								any
Desired Altitude, km	463 to 667	463 to 667								>37,000; 463 to 667
(n.mi.)	(250 to 360)	(250 to 360)								(>20,000; 250 to 360)
Acceptable Altitude, km	370 to 740	370 to 740								370 to 740
(n.mi.)	(>200 to 400)	(>200 to 400)								(>200 to 400)
Orientation:										
Observed Object Location										
Observed Object Brightness, mag., m_v	-2.5 to 18	-2.5 to 18								-2.5 to 18
Observation Field of View	1.45×10^{-3} rad (20 arcmin)	0.174 rad (10°, 600 arcmin)								1.45×10^{-3}, 0.174 (20, 600 arcmin)
Pointing Accuracy, rad	5×10^{-6}	5×10^{-6}, 2.4×10^{-5}							2.4×10^{-5}	5×10^{-6}
(arcsec)	(<1)	(<1) (5)							(5)	(< 1)
Pointing Stability, rad/obs time	5×10^{-6}	5×10^{-6}								5×10^{-6}
(arcsec/obs time)	(<1)	(< 1)								(< 1)
Slew Rate, max., rad/sec	1.74×10^{-3}	1.74×10^{-3}								1.74×10^{-3}
(arcsec/sec)	(360)	(360)								(360)
Slew Rate, min., rad/sec	5×10^{-6}	5×10^{-6}								5×10^{-6}
(arcsec/sec)	(< 1)	(< 1)								(< 1)
Pointing Hold Time, sec	2400 to 14,400	360 to 14,400								360 to 14,400
Data Requirements/Observation Cycle:										
Imaging Data / Desired Resolution (spatial or spectral)	5×10^{-6} (1 arcsec) > 40 cycles/mm 1.2×10^{-12} m (0.012 Å)	1.1×10^{-5} rad (2.3 arcsec) Acc: 1.45×10^{-5} rad (3 arcsec)							1.45×10^{-5} (3 arcsec) 2×10^{-10} (2 Å)	>40 cps/mm 1.1×10^{-5} rad (2.3 arcsec) 1.2×10^{-12} (0.012 Å)
Equiv. Image Format Size, mm	25.4 × 25.4	120 × 120 mm 100 x 100								25.4 × 25.4 & 100 × 100
Picture Elements/Image	~10^6	(10^9), 3×10^8								10^6 to 10^9
Images/Data Set	1 to 11	3 or more								4 or more
Images/Second	6.95×10^{-5} to 1	6.95×10^{-5} to 1								6.95×10^{-5} to 1
Photometric Resolution, %, bits	1,7	1,7								1,7
Equiv. Analog Data, MHz (Hz)	11	(1.78×10^8)*								(1.78×10^8)*
Equiv. Digital Data, bits/data set	(8×10^6)	1.12×10^8								1.2×10^8
Non-Imaging Data: Command Data, bps	< 100	< 200								< 300
Science/Exp. Data, bps	< 2000	< 1000								< 3000
Housekeeping Data, bps	~ 200	< 100								< 300
Special Requirements:										
Updating Cycle, Years	2	1								1 to 2
Mass, kg/yr (Weight, lb/yr)	240 (480)	68 (152)								287 (632)
Volume, m^3/yr (ft^3/yr)	0.68 (24)	0.226 (8)								0.91 (32)
Data Storage, bits	2.5×10^8	(> 2.5×10^8)								> 5×10^8

* Initial Electronic Imaging will be capable of a resolution of about 9 arcsec, improving to 3 arcsec; 1 arcsec for limited field.

Table 4-15. Predicted Schedules for Manned UV Telescopes



optical simulator type test equipment to the telescope apertures. Since the atmosphere blocks out most of the shorter-wavelength UV, at least two optical-pattern simulators capable of projecting parallel-ray test patterns into each of the two telescopes are required. A copy of the Space Station-contained as well as ground-based-remote control and monitoring position for each telescope, together with equivalent information processing equipment, should be available to enable integrated tests of total information flow loops. A photographic dark room equipped for film test, processing, and densitometry will also be needed. Suitable hoisting and transportation devices for the assembled telescopes are required.

4.10 SAFETY ANALYSIS

Some of the image converters and intensifiers as well as electronic-imaging cameras will employ rather high voltages. However, most of the high voltage will be suitably

protected to avoid inadvertent shock to servicing personnel. The telescope gimbals can present a hazard, particularly when one man is observing gimbal operation while another manipulates the gimbal controls. Adequate servicing and test procedures will need to be formulated if active gimbal-servo testing is to be accomplished over limited gimbal angles within the pressurizable servicing chambers.

4.11 AVAILABLE BACKGROUND DATA

a. Orbital Astronomy Support Facility (OASF) Study, NAS8-21023, McDonnell-Douglas Corporation, Huntington Beach, California.

b. Far Ultraviolet Astronomical Observations with All-Reflecting Schmidt Telescope, Northwestern University, 1969.

SECTION 5

HIGH-ENERGY STELLAR ASTRONOMY

5.1 GOALS AND OBJECTIVES

This group of experiments obtains information to enable accomplishment of stellar X-ray and gamma ray astronomy studies. Data obtained above the earth's atmosphere will give a better profile of energy distributions. The knowledge gained from previous high-energy astronomy survey flights will provide a basis for development of the experiments. This program element will enable multispectral correlation of stellar X-ray and gamma ray source data which can be analyzed immediately by the astronomical community. Man will be utilized for maintenance and repair to assure an extended experiment lifespan with the desired long viewing times.

The objectives of the Functional Program Element (FPE) are:

a. Extend our knowledge of astronomical phenomena through the use of X-ray and gamma ray experiments which will:

    1) Measure the flux, direction, and energy of high-energy radiation from 0.1 keV to the GeV range simultaneously for each source investigated.

    2) Measure the angular dimensions, intensity, and location of selected X-ray and gamma ray sources.

b. Evaluate the performance of manned space astronomy equipment which may be used as a basis for development of future manned mission equipment.

c. Develop and evaluate operational techniques and design philosophies for future manned space observations.

5.2 PHYSICAL DESCRIPTION

The high-energy stellar astronomy facilities are expected to consist of seven kinds of energy collectors and associated instruments enabling correlated measurements of direction, flux, and energy distribution (spectral) characteristics of radiation from any selected stellar source from 0.1 keV to 30 GeV as shown in Table 5-1. More detailed discussion of the facility items is given in the following paragraphs.

Table 5-2 shows basic characteristics of the energy collector/instrument assemblies. Figure 5-1 shows the integrated FPE configuration of the seven experiment facility items capable of pointing at the same source at the same time.

Table 5-1. Summary of High Energy Stellar Astronomy

EQUIPMENT CLASS	FACILITY ITEMS							SPECIAL EQUIPMENT										
	Wolter Type I Grazing Incidence X-Ray Telescope	Venetian Blind X-Ray Telescope	Asymmetric Crystal Cone Spectrometer/Polarimeter Assemblies	Large X-Ray Counter Array	Low Background Detector Array	High Resolution Gamma Ray Spectrometer	Large Area Spark Chamber	Aspect Sensor	Imaging Detector	Transmission Grating	X-Ray Proportional Counter	Mapping Module	Modulation Collimators	Bragg Spectrometer	Central Gas Source	6.0 to 400 keV Detector Units	Ge (Li) Detector/Refrigerator	Composite Alignment and Calibration Equipment
5.4.1 0.1 keV to 5 keV Low Energy X-Ray Telescope Experiments	●							●	●	●				●				●
5.4.2 0.1 to 20 keV X-Ray Source Mapping		●						●			●							●
5.4.3 6 to 10 keV Narrow Band Spectrometry and Polarimetry			●					●										
5.4.4 0.1 to 100 keV Large Area X-Ray Counter Array Measurements				●								●	●		●			●
5.4.5 6.0 to 400 keV Cosmic X-Ray Energy Spectra					●											●		●
5.4.6 0.06 to 10 MeV Gamma Ray Spectrometry (Low Background Detection)						●		●									●	●
5.4.7 10 MeV to 30 GeV High Energy Gamma Ray Measurements							●	●										●

Table 5-2. Characteristics of High Energy Stellar Energy Collector/Instrument Assemblies

PARAMETER	Grazing Incidence X-Ray Telescope	Venetian Blind X-Ray Telescope	Asymmetric Crystal Cone Spectrometer/ Polarimeter Assemblies (9)	Large X-Ray Counter Array	Low Background Detector Array for 6 to 400 keV Energy Spectra	High Resolution Gamma Ray Spectrometer	Large Area Spark Chamber			
Aperture Diameter, m	0.5	0.87×1.02		1.85×3.3						
Effective Area, cm^2	100	550 cm^2 @ 0.1 to 1.1 keV 270 cm^2 @ 1 to 5 keV	9×500	570/Unit	640	64	18,225			
Effective Focal Length, m		6.1								
Total Field of View, radian (arcmin)	4.4×10^{-3} (15)	1.75×10^{-3} by 7×10^{-2} (6×240)	1.75×10^{-2} (60)	1.05×10^{-2} (36)	2.6×10^{-2} (90)	0.53 (FWHM) (1800X, FWHM)	0.17 to 1.7×10^{-2} (600 to 60)			
Angular Resolution; On Axis, radian (arcmin) Poorest (in extended FOV), radian (arcmin)	9.7×10^{-6} (0.0333) 2.9×10^{-4} (1)	7.3×10^{-5} (0.25)	1.45×10^{-3} (5)	1.75×10^{-3} (6)	4.36×10^{-3} (15) 4.36×10^{-3} (15)	1.75×10^{-3} (6) 1.75×10^{-4} (1800)	2.9×10^{-4} (1) 1.75×10^{-3} (6)			
Obscuration of Aperture, %	0.20									
Minimum Energy	0.1 keV	Two ranges: 0.1 keV, 2 keV	6 keV	0.1 keV	6 keV	0.06 MeV	10 MeV			
Maximum Energy	5 keV	6 keV, 20 keV	10 keV	100 keV	400 keV	10 MeV	30 GeV			
Facility Item Assembly Envelope, m (ft)	$0.61\ D \times 3.97\ L$ $(2\ D \times 13\ L)$	$1.02 \times 0.87 \times 8.1$ $(3.33 \times 2.83 \times 26.5)$	9 dispersed units of $0.76\ D \times 0.61\ L$ $(2.5\ D \times 2\ L)$	$0.61 \times 1.07 \times 3.96$ $(2 \times 3.5 \times 13)$	$1.6 \times 1.6 \times 0.49$ $(5.25 \times 5.25 \times 1.6^*)$	$1.22 \times 0.92 \times 0.76$ $(4 \times 3 \times 2.5)$	$2.02\ D \times 1.83\ L$ $(6.66\ D \times 6\ L)$			
Volume, m^3 (ft^3)	1.18 (41.8)	7.14 (252)	1.24 (43.7)	2.6 (91)	1.25 (44)	0.85 (30)	4.9 (173)			
Weight, kg (lb)	145 (320)	566 (1250)	245 (540)	226 (497)	236 (520)	200 (440)	1400 (3080.0)			
Associated Experiment Envelope, m (ft)	$0.61\ D \times 2\ L$ $(2\ D \times 2\ L)$	$0.61 \times 0.61 \times 0.37$ $(2 \times 2 \times 1.25)$	$0.61 \times 0.92 \times 0.3$ $(2 \times 3 \times 1)$	(Included above)	$0.4 \times 0.4 \times 0.7$ $(1.3 \times 1.3 \times 2.3^*)$	(Included above)	(Included above)			
Volume, m^3 (ft^3)	0.18 (6.3)	0.4 (5)	0.17 (6)	(Included above)	0.1 (3.8)	(Included above)	(Included above)			
Weight, kg (lb)	54.5 (120)	91 (200)	27.3 (60)	(Included above)	28.6 (63)	(Included above)	(Included above)			
Total Integrated Envelope, m (ft)	$0.61\ D \times 6.93\ L$ $(2\ D \times 15\ L)$									
Gross Volume per Assembly, m^3 (ft^3)	1.3 [illegible]	7.3 (257)	1.4 (49.7)	2.6 (91)	1.36 [illegible]	0.85 (30)	4.9 (173)			
Gross Weight per Assembly, kg (lb)	200 (440)	658 (1450)	272 (600)	225 (497)	264 (583)	200 (440)	1398 (3080)			

*Includes access between units.

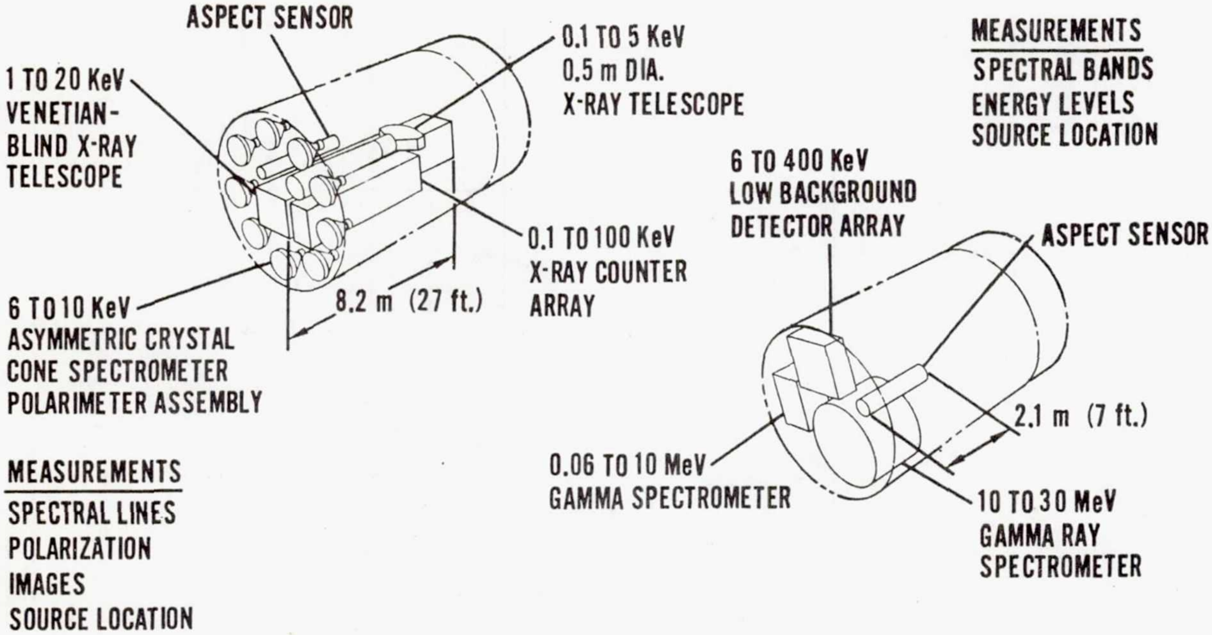


Figure 5-1. Integrated High-Energy Stellar Astronomy Experiment Facilities Typical Configurations

5.2.1 WOLTER TYPE I GRAZING INCIDENCE X-RAY TELESCOPE. The telescope assembly will consist of Wolter type I grazing incidence X-ray telescope with interchangeable detector and spectrometer systems at the foci. (See Figure 5-2.) The telescope will allow spatial information to be obtained with a resolution which can be varied between a few seconds of arc and one arcmin. The X-ray imaging detector and Bragg spectrometer will enable broadband photometry and high spectral resolution studies.

Figure 5-3 shows various fields possible with Wolter type telescopes to be discussed further in the following paragraphs since type I behavior of the telescope is utilized. The telescope will have a 0.51 m (20 in.) diameter "Wolter Type I" mirror with a focal length of 3.6 m (140 in.) and a collecting area of approximately 100 cm^2. The telescope is contained in a volume roughly 4 m (13 ft) long by 0.61 m (2 ft) in diameter. Weight would be approximately 145 kg (320 lb). The telescope will be capable of accommodating an imaging detector and crystal spectrometer sequentially at the focus.

5.2.2 VENETIAN BLIND X-RAY TELESCOPE (0.1 TO 20 keV). The Venetian blind X-ray telescope assembly consists of two independent detection subassemblies about 8.2 m (27 ft) long such as shown in Figure 5-4. Each detection subassembly will be comprised of a nested set of parabolic reflectors that focus X-rays onto an array of

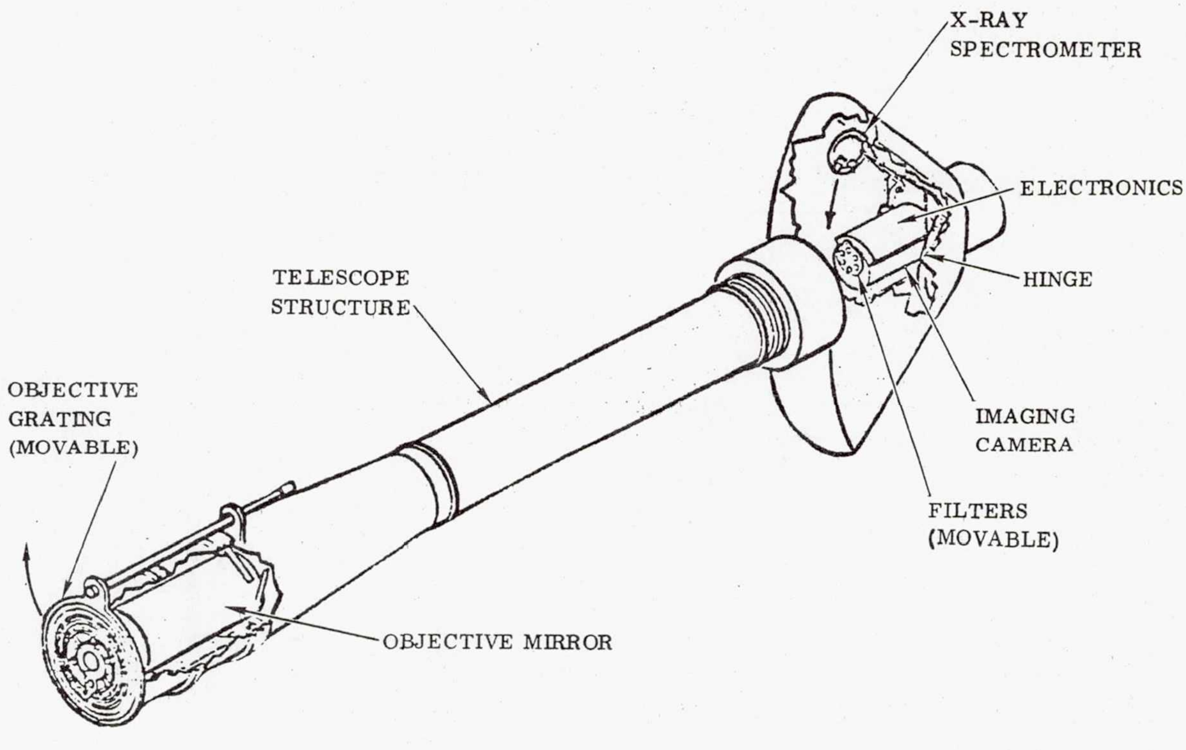


Figure 5-2. X-Ray Telescope and Spectrometer

thin-window gas-flow proportional counters. An aspect photometer is also needed and is the same as utilized for the grazing incidence X-ray telescope in Section 5.2.1 since all the telescopes in the high energy stellar astronomy facility are pointed in the same direction. Two systems are mounted side by side to provide redundancy.

The mirrors are made of Kanigen coated beryllium or of a vitreous material. An appropriate thin-window counter array would consist of an assembly of four X-ray sensitive elements, the aggregate being surrounded by a U-shaped anticoincidence counter.

By running each detection element in anticoincidence with adjacent counting elements and using pulse-rise time discrimination, the unwanted background from cosmic rays can be greatly reduced. Two spectral ranges are utilized: 0.1 to 6 keV and 2 to 20 keV. Although the second range is also included in the coverage of the Section 5.2.5 large X-ray counter array, the 2 to 20 keV capability is retained because of the higher angular resolution capability of the Venetian blind telescope.

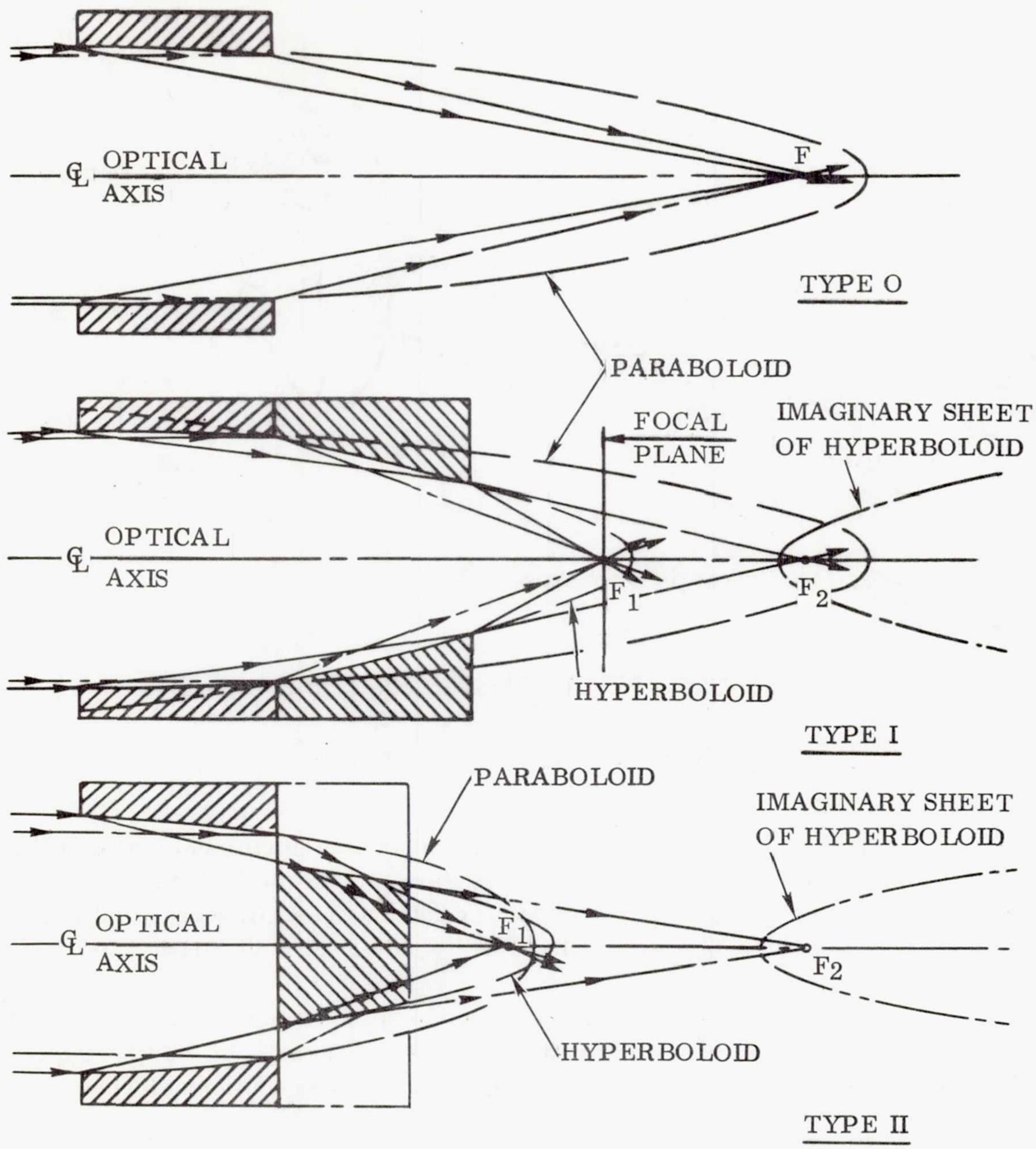


Figure 5-3. Wolter X-Ray Telescopes

5.2.3 ASYMMETRIC CRYSTAL CONE SPECTROMETER/POLARIMETER ASSEMBLIES

5.2.3.1 Functional Description. The asymmetric crystal cone array consists of nine large-area (~500 cm^2 effective collecting area), high-resolution (20 eV and 120 eV), polarization-sensitive collectors tuned to select line and continuum locations in the 6 to 10 keV range. Two spectral resolutions are proposed: $E/\Delta E$ = 350 and 60 at a

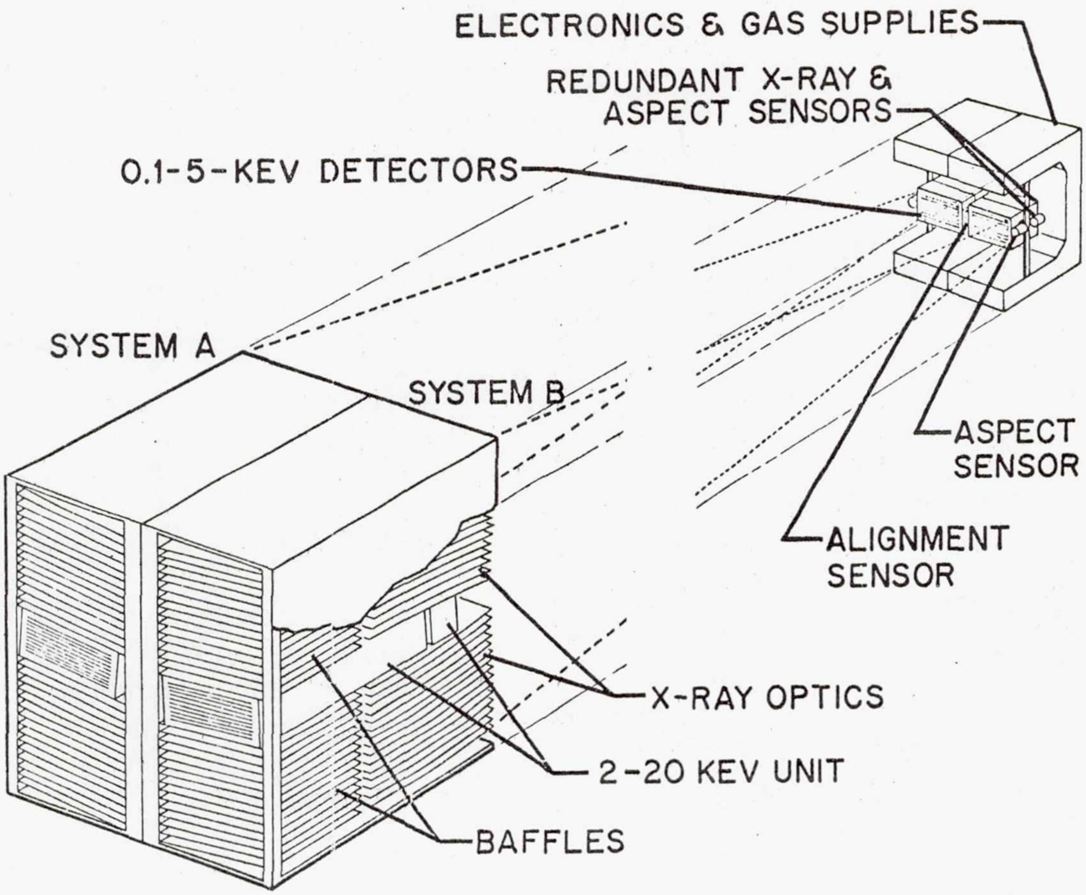
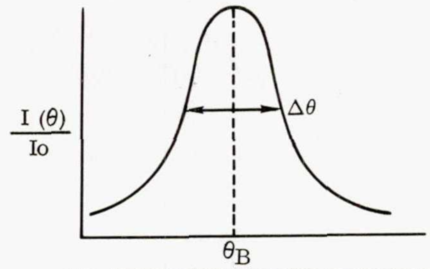


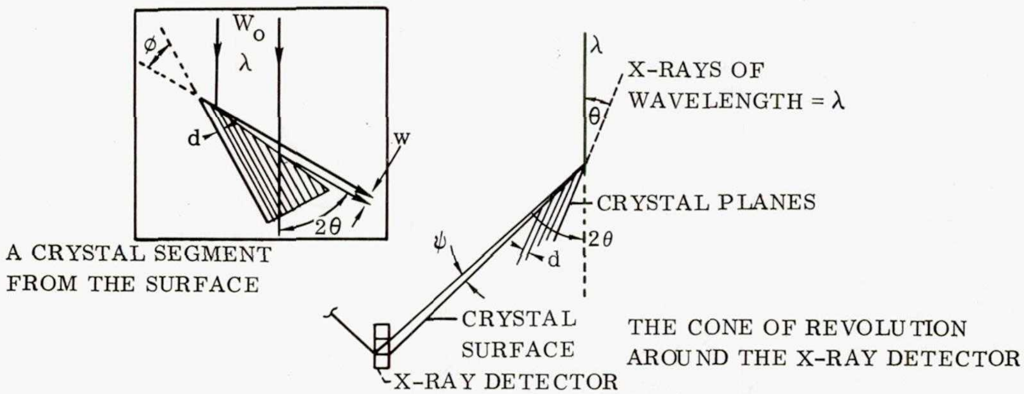
Figure 5-4. Venetian Blind X-ray Telescope Assembly

photon energy of 7 keV. A flux of 2×10^{-4} photons cm^{-2} sec^{-1} keV^{-1} ($\sim 5 \times 10^{-5}$ Sco X-1) at 6 keV can be established with each 120 eV bandwidth collector at a 3σ confidence level in an integration time of 1000 sec. The high-resolution collectors are expected to make statistically significant emission line strength measurements on sources of the same strength in the same time interval. Linear polarization can be detected in 1400 seconds with a precision of 1% in a continuum source of strength equivalent to the Crab Nebula at 6 keV. The instrument has a field of view of 1.7×10^{-2} rad (60 arcmin) FWHM (10^{-3} sr) and allows X-ray star position determination, through scanning techniques, with an accuracy of 1.4×10^{-3} rad (5 arcmin). Measurements are performed simultaneously in all nine channels so that spectrometric and polarimetric observations may be carried out on rapidly time varying sources as well as on the more constant ones.

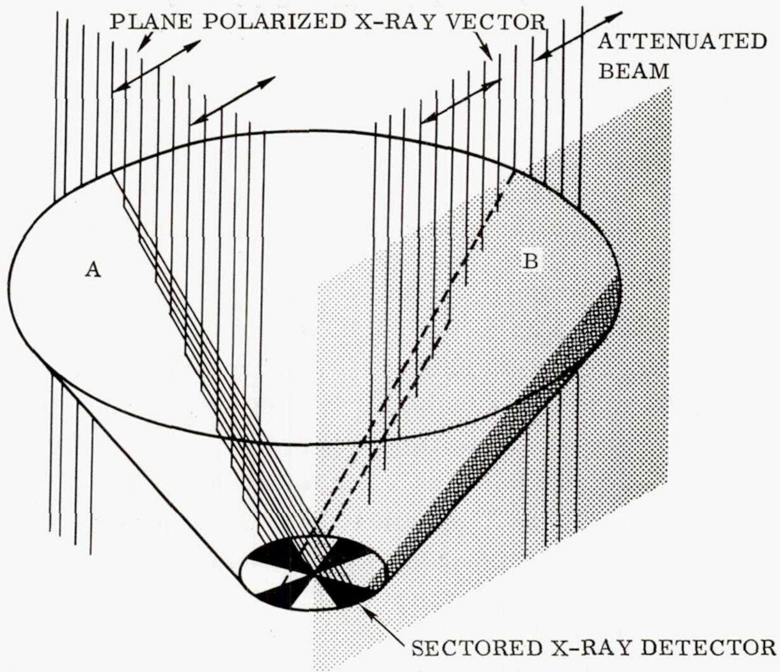
Each asymmetric channel cone functions generally in accordance with the following discussion. When the surface of a crystal is cut at an angle ϕ to the diffracting planes, as in Figure 5-5A, B, C, the incident and diffracted beams are asymmetric with respect to the crystal surface normal. Hence, the incident beam width W_0 is



(A) ROCKING CURVE PROFILE



(B) ASYMMETRIC BRAGG CONCENTRATING CONE



(C) ASYMMETRIC BRAGG COSMIC X-RAY POLARIMETER

Figure 5-5. Asymmetric Crystal Cone Functions

concentrated to width w in contrast to the symmetric Bragg case where no concentration occurs. We utilize this geometrical relationship to maximize the ratio of collecting to detecting area by constructing a cone of diffracting crystals.

This concentrating device consists of a cone covered on the inner surface with a mosaic of small asymmetric Bragg crystals oriented to diffract incident, parallel X-rays toward the apex where an X-ray sensor is located. Note that incident rays fulfilling the Bragg condition are mapped to definite points on the sensor. This is shown more clearly in Figure 5-5B and C. Since θ_B is constant over the entire cone, the cone selects from the incident flux a narrow energy band such as 20 ev for LiF and 120 ev for graphite and diffracts on to the X-ray sensor.

The same figure also shows polarization effects. Incident X-rays which have their polarization vectors aligned in the plane of the incident and diffracted beams are attenuated; polarization vectors which are perpendicular to the plane of the incident beams are unaffected. The method measures linear polarization by comparing counting rates of individual sectors of an X-ray sensor located at the cone apex.

5.2.3.2 Integrated Configuration Description. The integrated facility group will consist of nine individual X-ray concentrator/detector units and an output data combining unit with supporting structure and instrumentation. Each unit is aligned with the spacecraft axis and is constructed to make continuous, simultaneous measurements of intensity and polarization in several narrow X-ray energy bands in the 6 to 10 keV region. In the typical configuration of Figure 5-1, the units are arranged around the periphery of the end of a supporting vehicle which also contains other associated experiments. Table 5-2 includes dimensions and characteristics of the array of nine assemblies plus one combining electronics unit. Figure 5-6 shows a typical asymmetric cone spectrometer/polarimeter assembly. Each of the nine assemblies feeds output signals to a combining electronics unit which formats the data for transfer to a local computer or for transmission back to earth.

5.2.3.3 Individual Unit Electronics. The flight electronics consist of the equipment and logic circuitry required to process the signals from the sensors (see Figure 5-7). This includes the high voltage regulated supply for the sensors with its logically controlled ON/OFF switch and the power converters and regulators which operate from a 28-volt unregulated supply.

The preamplifiers are of the charge sensitive type with a sensitivity of 10^{14} volts/coulomb (deposited within 10^{-7} second) and a decay time constant of 10^{-6} second. Digitally controlled step attenuators follow the preamplifiers and may change the gain by command to compensate for long term gain changes in the sensor.

The window discriminators follow the attenuators and produce a pulse (1 μsec) for each event above threshold with the proper pulse shape. They also gate the analog pulse of the event onto a common buss for pulse height analysis.

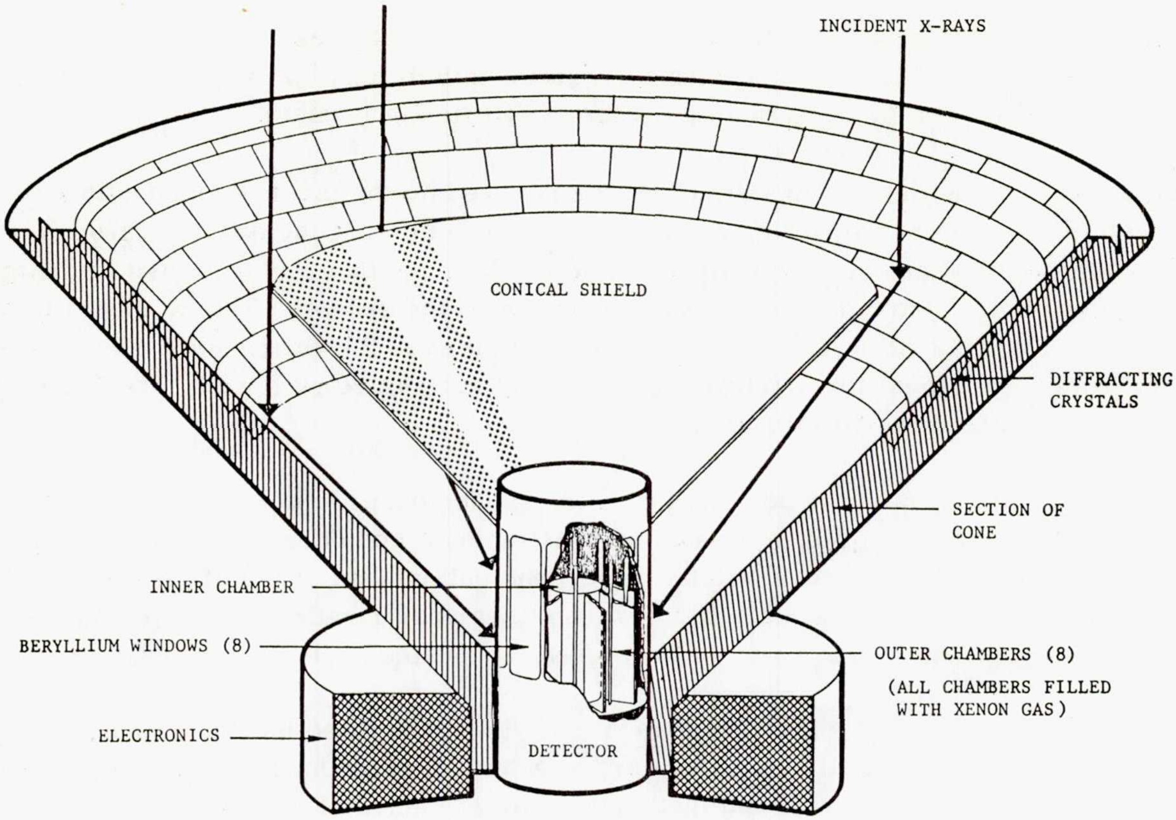


Figure 5-6. Detail of Sensor and Inner Shielding

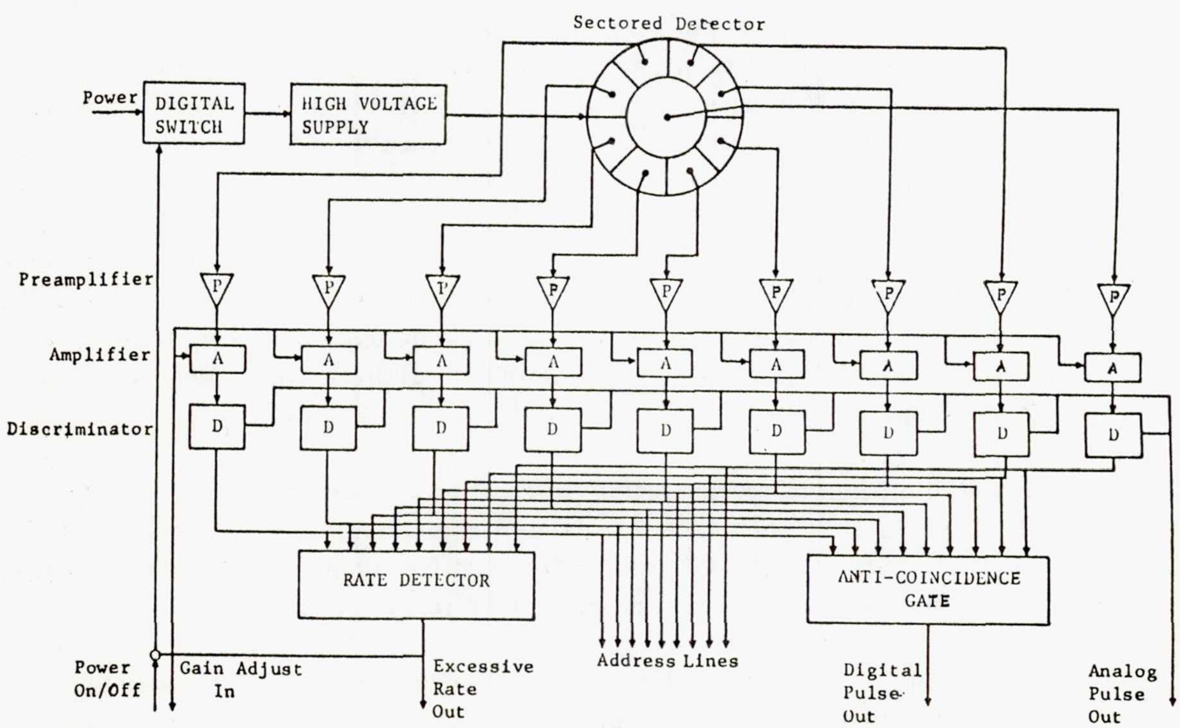


Figure 5-7. Schematic of X-ray Unit with Sectored Detector

A rate gate combines the outputs from the eight window discriminators in an OR fashion and triggers a monostable multivibrator for a combined rate within an energy window. The pulse thus produced turns off the high voltage supply for a discrete time interval to protect the sensor from excessive counting rates, such as produced by trapped radiation belts.

The anti-coincidence gate delivers an output for each singular input which determines whether the event will be recorded or not.

Each of the eight sectored counter chambers is monitored independently and operated in anticoincidence with all others to reduce the background due to charged cosmic rays. The central, cylindrical chamber is also operated in anticoincidence with each outer chamber to further reduce counts induced by radiations other than X-rays.

An electronic window-discriminator is associated with each of the outer eight counting chambers and adjusted to select only X-rays whose energies are $E_c \pm 500$ eV, where E_c is the photon energy diffracted by a particular asymmetric Bragg cone.

To allow for any gas gain changes that may occur during the mission, the pulse height spectrum from each counting chamber is sequentially monitored over a nominal energy range 5 to 15 keV. If changes occur, commands are provided to alter the electronic gain of each channel.

During passage through the South Atlantic Anomaly or during large solar particle events, the proportional counters are automatically turned off to avoid damage caused by excessive counting rates. After emerging from a high radiation region and when radiation levels have returned to normal, the detectors are automatically returned to normal operation.

5.2.3.4 Combining Unit Electronics. A block diagram of the circuitry for the entire flight instrument consisting of up to nine individual X-ray units and an output combining unit is shown in Figure 5-8.

a. Memory Units. The memory units are tied to pairs of detectors and record events according to sector by incrementing the four bit number stored at the sector address. They are composed of a 16×4 bit array with memory address buffer, accumulator, and output buffer.

b. Pulse Height Analyzer. The 32-channel pulse height analyzer selects for analysis each detector according to a predetermined automatic sequence. It analyzes the analog signal from the detector that has exceeded threshold and passed through the anticoincidence circuit. The count in the memory at the address of the pulse height is incremented as a result of the analysis.

c. Readout and Control. The readout and control circuitry receives a reference frequency from the clock, produces control frequencies from this, and sequentially

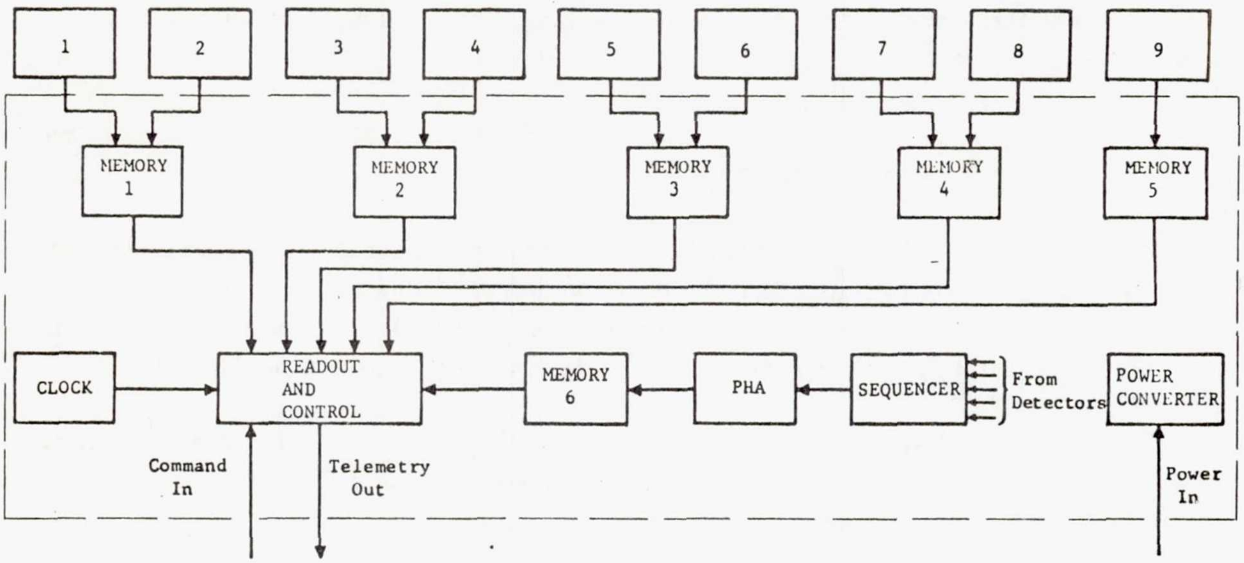


Figure 5-8. Block Diagram of Flight Instrument

reads the contracts in each memory unit for transfer to a local computer or for transmission to the ground station.

d. Automatic Checkout. The combining unit will also contain circuits enabling automatic periodic checkout and failure monitoring. Local controls and displays will be provided to enable manned maintenance as well as remotely controlled operations.

5.2.4 LARGE X-RAY COUNTER ARRAY. The large X-ray counter array and its associated instruments are listed by sub-modules in Table 5-3 which also gives some estimates of the dimensions. The array equipment can be used for measurements in the 0.1 keV to 100 keV energy range which can be time correlated with both focused X-ray telescope measurements and higher energy stellar astronomy measurements.

5.2.5 LOW BACKGROUND DETECTOR ARRAY. The low background detector array consists of four detector units capable of measuring flux and spectra in the 6 keV to 400 keV range. Each detector axis is parallel to each X-ray telescope axis of Sections 5.2.1 and 5.2.2. All detectors are aligned to each other to $\pm 4.4 \times 10^{-3}$ rad (1/4°) with respect to one another. The individual detector units are fairly heavy and require strong mounting flanges to hold them in the array during the launch phase. A collimator is used to direct gamma rays to the detector units. Figure 5-9 shows a cross section of one of the detectors. Each detector will have characteristics indicated in Table 5-4 for 2.6×10^{-2} rad (1-1/2°) of view.

Table 5-3. Large X-Ray Counter Array Envelope, Weights, and Power

EXPERIMENT EQUIPMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m (ft)
3 Mapping Modules	30	(66.3)	[0.27	(9.58)]	
Front Section			0.03	(1.03)	0.56×1×0.05 (1.85×3.3×0.17)
Instrument Section			0.24	(8.55)	0.56×1×0.43 (1.85×3.3×1.4)
Modulation Collimator Modules	57	(125.4)	[0.46	(16.45)]	
Front Section			0.22	(7.9)	0.56×1×0.4 (1.85×3.3×1.3)
Rear Section			0.24	(8.55)	0.56×1×0.43 (1.85×3.3×1.4)
Central Gas Supply (two press. spheres)	95	(210)	0.34	(12)	0.61×0.61×1.2 (2×2×4)
Central Data Processor	6.8	(15)	0.08	(3)	0.31×0.91×0.31 (1×3×1)
Estimated for Exp.Equipment	188	(416.7)	11.6	(41.01)	0.61×1.2×0.39 (2×3.5×12.8)
Configuration Mounting Frame	36.4	(80.0)	0.54	(19.3)	
Totals Estimated for Assembly	225	(496.7)	1.7	(60.04)	0.61×1.2×0.4 (2×3.5×13)

5.2.6 HIGH RESOLUTION GAMMA RAY SPECTROMETER. The high resolution gamma ray spectrometer assembly consists of 4 Ge(Li) detector crystals packaged in a detector unit 0.31 m (12 in.) in diameter and 0.34 m (13 in.) long. The detector units also contain four CsI(Na) crystals which scintillate. Fourteen photo multiplier tubes are utilized in the unit to view the anticoincidence scintillation crystals. Figure 5-10 shows details of the Ge(Li) detector and the solid cryogen refrigerator. The following tabulation lists component unit dimensions and mass.

Unit	Dimensions, m (ft)	Volume, m^3	(ft^3)	Mass (Weight), kg	(lb)
Detector	0.15D × 0.18L (0.5D×0.6L)	0.03	(0.1)	9.1	(20)
Shield & Housing	0.31D × 0.34 (1D × 1.1L)	0.86	(1.1)	108	(240)
Electronics Package	0.31×0.31×0.31 (1×1×1)	0.03	(1)	9.1	(20)
Cryogenic Refrigerator	0.61×0.61 (2d × 2L)	0.11	(4)	45.4	(100)
Structure	Included in Assembly	In Assembly		27.2	(60)
Total Assembly	1.22×0.91×0.76 (4×3×2-1/2)	0.85	(30.0)	200	(440)

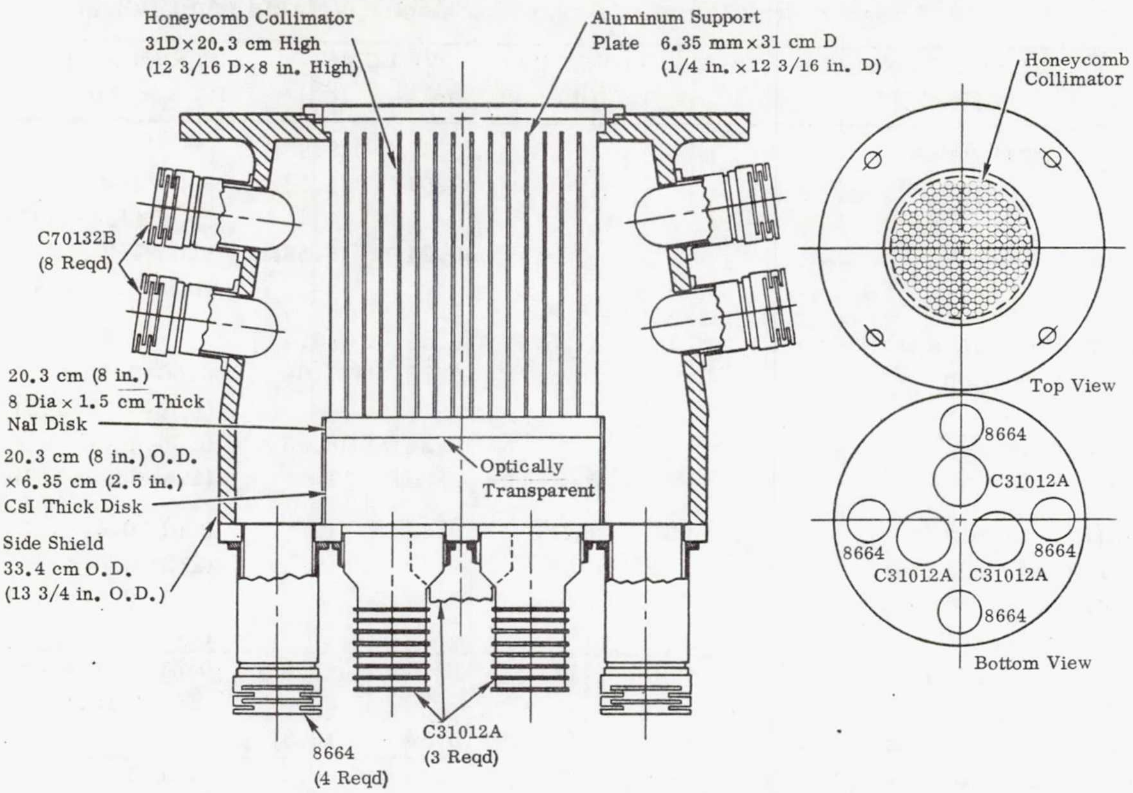


Figure 5-9. Cross-section of a Single Detector Unit Showing the Crystals, PM Tubes and Mounting Bracket

Table 5-4. Summary of Detector Characteristics

Angular Response	0.05 rad (3°) Full Width at Half Maximum*
Solid Angle:	2.2×10^{-3} steradians at 0.05 rad (3°) FWHM 1.0×10^{-3} steradians at 0.035 rad (2°) 0.55×10^{-3} steradians at 0.026 rad (1-1/2°)*
Sensitive Area:	640 cm^2
Telescope Factor:	1.36 cm^2 steradians at 0.05 rad (3°) 0.62 cm^2 steradians at 0.035 rad (2°) 0.34 cm^2 steradians at 0.026 rad (1-1/2°)
Photon Energy Range:	6 keV (75% FWHM Energy Resolution) to 400 keV (15% Efficiency)
Background:	$< 2 \times 10^{-5}$ photons/cm^2/sec/kev over 6 to 400 keV energy range (calculated from semi-empirical model)

* The 0.05 rad (3°) FWHM design has been thoroughly worked out. It is believed the aperture can be reduced to 0.035 rad (2°) or 0.026 rad (1.5°) by either of two alternatives now under study.

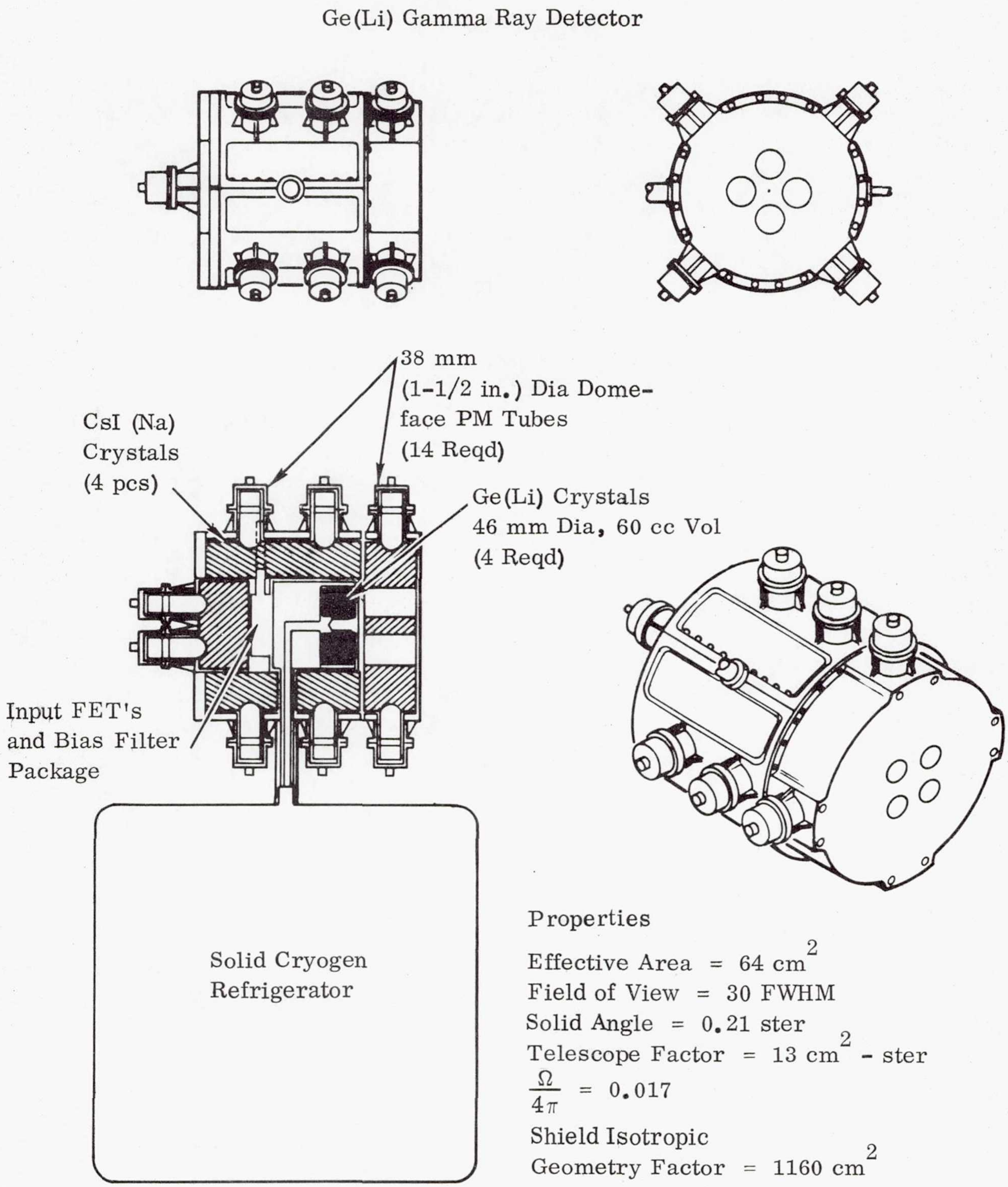


Figure 5-10. Ge (Li) Detector and Refrigerator

5.2.7 LARGE AREA SPARK CHAMBER. The large area spark chamber, with optional triggering modes for measurements of radiation from galactic or extragalactic sources in the energy range from 10 MeV to 30 GeV, consists of: A converting spark chamber of 81 plates with thickness 0.007 radiation length, a defining spark chamber of 17 plates with thickness 0.007 radiation length, two sets of orthogonal coincidence scintillator strips, and a high-Z detector (probably CsI or NaI). Figures 5-11 and 5-12 indicate details of the large area spark chamber. Weights and dimensions are presented in Table 5-5. An anticoincidence shield encloses the total assembly down to the plane of counter B in Figure 5-11. The spark chamber has an acceptance area of 135 × 135 cm (4.4 × 4.4 ft) with a conversion efficiency of 0.3 at 200 MeV.

A triggering technique is used to minimize spurious pulsing of the spark chamber.

5.3 EXPERIMENT REQUIREMENTS SUMMARY

Table 5-6 summarizes requirements of the seven experiments which operate simultaneously. All the energy collector instrument assemblies from the seven experiments receive radiation from the same observed source direction. Hence the requirements combine arithmetically in case of power loading, data output, etc. However, for requirements such as pointing accuracy and angular stability, the most severe (least error) requirement applies for the total set of instruments since each instrument axis is parallel to that of the others.

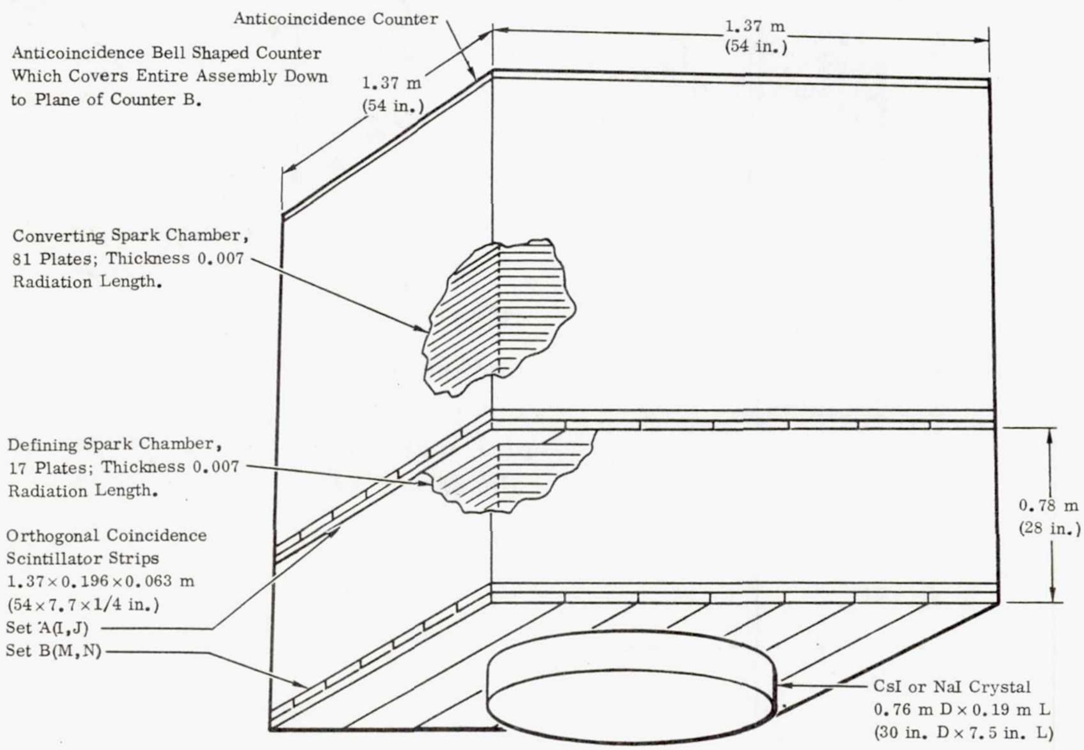


Figure 5-11. General Spark Chamber Design (Typical Construction)

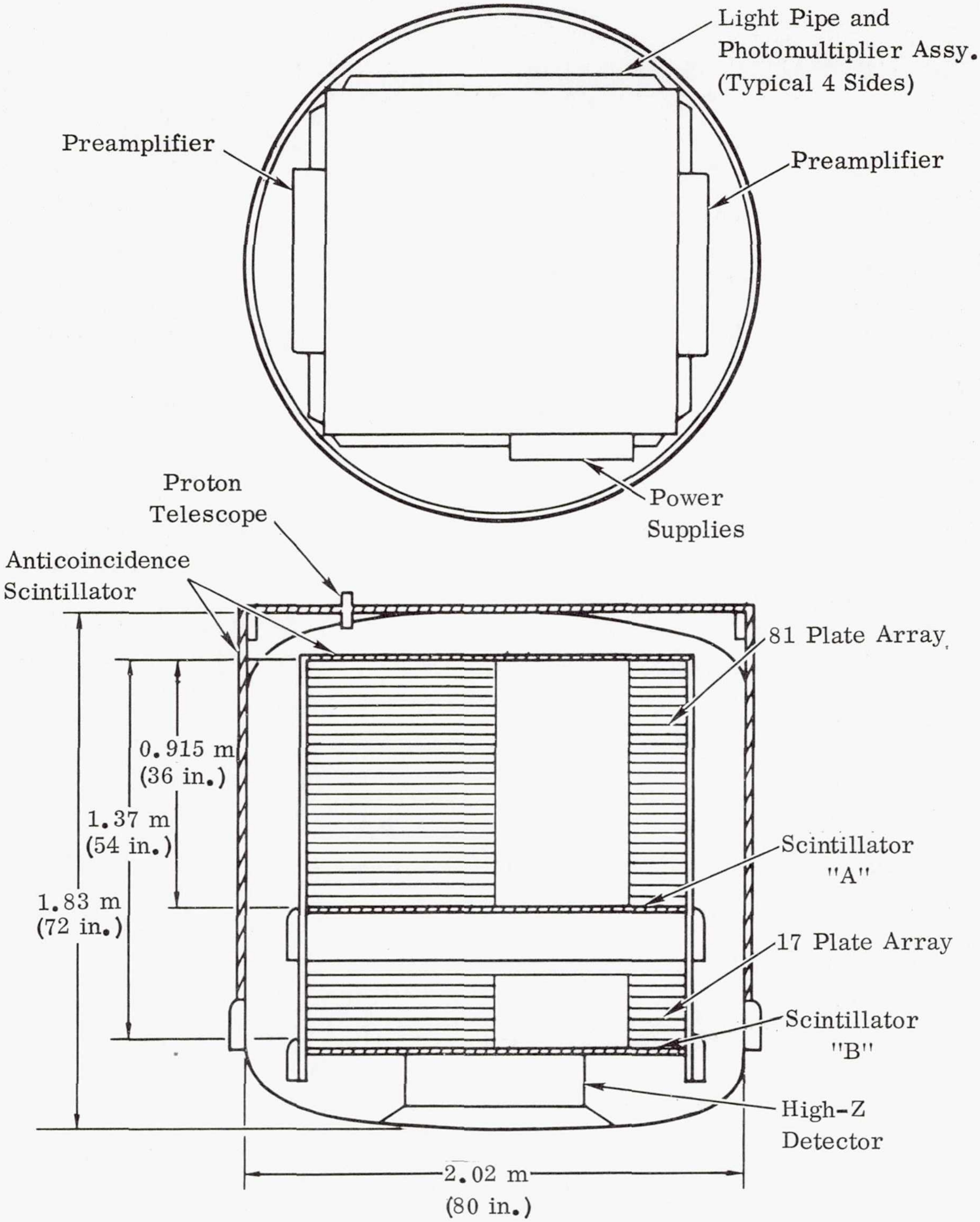


Figure 5-12. Spark Chamber and Pressure Bell

Table 5-5. Large Area Spark Chamber Weights, Volume and Dimensions

Ref. No.	EQUIPMENT ITEM	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)
a	Anticoincidence Shield			Bell shaped, 2.02 × 1.53 (6.66 × 5)
b	Converting Spark Chamber			1.4×1.4×0.91 (4.5×4.5×3)
c	Refining Spark Chamber			14 ×14 ×0.3 (4.5 ×4.5 ×1)
d	Orthogonal Coincidence Scintillator Straps A and B			A = 1.4×1.4×0.15 (4.6×4.6×0.5) approx. B = 1.4×1.4×0.06 (4.6×4.6×0.2) approx.
e	High Z Detector (CsI or NaI)			0.76D× 0.19L (2.5D × 0.625L)
f	Light Pipe and Photomultiplier Assemblies (4)			Included in assembly
g	Preamplifiers			Included in assembly
h	Counters			Included in assembly
i	Power Supplies			
	TOTAL			
	Large Area Spark Chamber	1400 (3080)	5.8 (204)	2.02D×1.83L (6.6D×6L)

5.4 EXPERIMENT PROGRAM

The experiment program consists of simultaneous operation of seven classes of high energy stellar astronomy correlated measurements on selected sources in the spectral region from 0.1 keV to 30 GeV. These requirements include low-energy X-ray telescope measurements (0.1 to 5 keV), X-ray source mapping (0.1 to 20 keV), narrow band spectrometry and polarimetry (0.1 to 20 keV), X-ray measurements (0.1 to 100 keV), cosmic X-ray energy spectra (6 to 400 keV), gamma ray spectrometry or low background detection (0.06 to 10 MeV), and high energy gamma ray measurements (10 MeV to 30 GeV). The following sections describe the representative experiments.

Table 5-6. High Energy Stellar Astronomy Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
5.4.1 Low Energy X-Ray Experiment (0.1 to 5 keV)	200 (440)	1.3 (47.1)	0.61 × 4.6 (2D × 15L)	Average: 50 Peak: 100 Standby: 50	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astrophysicist	Temp. Limits: 273 to 293 °K Ops Atmosphere: 0 to 10^5 N/m^2, 1.33 x 10^{-4} N/m^2 (0-15 psi, <10^{-6} torr) Gravity Level: 10^{-4} g, operating Radiation Sensitivity: <1 millirad/hr	Setup: 8 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: 3.6 x 10^3 Images/Sec: 1 Digital Picture Data: 3.96 x10^4 bps Non Imaging Data: Command 128 bps Science/Exps: 3194 bps Housekeeping: 128 bps	Pointing Accuracy: Hi-Res: 9.0x10^{-6}rad (2 arcsec) Pointing Stability: 5 x 10^{-6} rad (1 arcsec) Max Slew Rate: 0.1 rad/min (6° per min) Min Slew Rate: 5 x 10^{-6} rad/sec (<1 arcsec/sec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 270 to 740 km (> 200 to 400 n.mi.)	Timing Accuracy: 1x10^{-7} with millisec readout. Needs aspect sensing, with 7.5 x10^5 to 7 x 10^6 bps date rate
5.4.2 X-Ray Source Mapping (1 to 20 keV)	658 (1450)	0.73 (25.7)	1.02x0.87x8.1 (3.33x2.83x26.5)	Average: 42 Peak: 93 Standby: 42	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astrophysicist	Temp. Limits: 272 to 274 °K Ops Atmosphere: 0 to 10^5 N/m^2, 1.33 x 10^{-4} N/m^2 (0-15psi, <10^{-6} torr) Gravity Level: 10^{-4} g, operating Radiation Sensitivity: < 1 millirad/hr	Setup: 4 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: - Images/Sec: - Digital Picture Data: - Non Imaging Data: Command: 17 bps Science/Exps: 4600 bps Housekeeping: 10 bps	Pointing Accuracy: 360 arcsec Pointing Stability: 2.9x10^{-4} rad/obs per (60 arcsec/obs per) Max Slew Rate: 0.1 rad/min (360 arcsec/sec) Min Slew Rate: 5 x 10^{-6} rad (1 arcsec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (>200 to 400 n.mi.)	Timing Accuracy: 1.66 x 10^9 *Avoid high flux high energy parts of South Atlantic anomaly. Need aspect sensing
5.4.3 Narrow Band Spectrometry & Polarimetry (6 to 10 keV)	272 (600)	1.4 (47.2)	9 pkgs 0.76D x 0.61L (2.5D x 2L) Plus 1 pkg 0.61x0.92x0.3 (2 x3 x 1)	Average: 50 Peak: 50 Standby: 50	Astronomer/ Astrophysicist	Temp. Limits: 272 to 274 °K Ops Atmosphere: 0 to 10^5 N/m^2 1.33x10^{-4} N/m^2 (0-15 psi, <10^{-6} torr)	Setup: 9 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: - Images/Sec: - Digital Picture Data: - Non Imaging Data: Command: 56 bps Science/Exps: 1000 bps Housekeeping: 180 bps	Pointing Accuracy: 5 x 10^{-6} rad (1 arcsec) Pointing Stability: 5x10^{-6} rad/obs (1 arcsec/obs) Max Slew Rate: 2.9 x10^{-4} rad/sec (360 arcsec/sec) Min Slew Rate: 5x10^{-6} rad/sec (1 arcsec/sec) Pointing Hold Time: 1800 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 (200 to 400 n.mi.)	

Table 5-6. High Energy Stellar Astronomy Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
5.4.4 X-Ray Measurements (0.1 to 100 keV)	225 (497)	2.6 (91)	0.61x1.07x3.96 (2x3.5 x 13)	Average: 23 Peak: 100 Standby: 23	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astronaut	Temp. Limits: 272 to 274 °K Ops Atmosphere: 0 to 10^5, 1.33×10^{-4} N/m^2 (0-15 psi, <10^{-6} torr) Gravity Level: - Radiation Sensitifity: -	Setup: 8 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: - Images/Sec: - Digital Picture Data: - Non Imaging Data: Command: 20 bps Science/Exps: 1760 bps Housekeeping: 20 bps	Pointing Accuracy: 360 arcsec Pointing Stability: 2.9×10^{-4} rad/obs 60 arcsec/obs Max Slew Rate: 0.1 rad/min (6°/min) Min Slew Rate: 5×10^{-6} rad/sec (<1 arcsec/sec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (>200 to 400 n.mi.)	
5.4.5 Cosmic X-Ray Energy Spectra (6.0 to 400 keV)	264 (573)	1.36 (48)	1.6x1.6 x0.49 (5.25x5.25x1.6) plus 0.4x0.4x0.7 (1.3x1.3x2.3)	Average: 10 Peak: 11 Standby: 10	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astrophysicist	Temp. Limits: 288 to 293 °K Ops Atmosphere: 0 to 10^5 N/m^2, 1.33×10^{-4} N/m^2 (0-15 psi, <10^{-6} torr) Gravity Level: - Radiation Sensitivity: < 1 millirad/hr	Setup: 4 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: - Images/Sec: - Digital Picture Data: - Non Imaging Data: Command: 8 bps Science/Exps: 4000 bps Housekeeping: 20 bps	Pointing Accuracy: 2.62×10^{-3} rad (900 arcsec) Pointing Stability: 2.62×10^{-4} rad/obs (90 arcsec/obs) Max Slew Rate: 0.1 rad/min (6°/min. Min Slew Rate: 5×10^{-6} rad/sec (<1 arcsec/sec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (< 200 to 400 n.mi.)	
5.4.6 Gamma Spectrometry (0.06 to 10 MeV)	200 (440)	0.85 (30)	1.22x0.92x0.76 (4 x 3 x 2.5)	Average: 20 Peak: 30 Standby: 20	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astrophysicist	Temp. Limits: 273 to 303 °K Ops Atmosphere: 0 to 10^5 N/m^2, 1.33×10^{-4} N/m^2 (0-15 psi, <10^{-6} torr) Gravity Level: - Radiation Sensitivity: < 1 millirad/he	Setup: 8 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: Images/Sec: - Digital Picture Data: - Non Imaging Data: Command: 7 bps Science/Exps: 2500 bps Housekeeping: 20 bps	Pointing Accuracy: 1.74×10^{-2} rad (3600 arcsec) Pointing Stability: 1.7×10^{-3} rad/obs (360 arcsec/obs) Max Slew Rate: 0.1 rad/min (6°/min. Min Slew Rate: 5×10^{-6} rad/sec (<1 arcsec/sec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (>200 to 400 n.mi.)	Timing Accuracy: 1×10^{-7} with 0.1 millisec resolution

Table 5-6. High Energy Stellar Astronomy Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
5.4.7. High Energy Gamma Ray Measurement (10 MeV to 30 GeV)	1398 (3080)	5.8 (2.02)	2.02D x1.83L (6.66D x 6L)	Average: 48 Peak: 50 Standby: 48	In Space: Physicist/ Astronaut Ground Based Monitoring and Control: Astronomer/ Astrophysicist	Temp. Limits: 263 to 303° K Ops Atmosphere: 0 to 10^5 N/m^2, 1.33 x 10^{-4} N/m^2 (0-15 psi, <10^{-6} torr) Gravity Level: - Radiation Sensitivity: < 1 millirad/hr	Setup: 8 Ops Cycle: 0.83 to 24 Maintenance: 4	Picture Elements Per Image: - Images/sec: - Digital Picture Data: - Non Imaging Data: Command: 7 bps Science/Exps: 5100 bps Housekeeping: 20 bps	Pointing Accuracy: 1.73 x 10^{-3} rad (360 arcsec) Pointing Stability: 2.9 x10^{-4} rad/obs (60 arcsec/obs) Max Slew Rate: 0.1 rad/min (6°/min) Min Slew Rate: 5 x 10^{-6} rad/sec (< 1 arcsec/sec) Pointing Hold Time: 3000 to 86,400 sec	Desired Incl: 0° Acceptable Incl: 55° to 0° Desired Alt: 740 to 930 km (400 to 500 n.mi.) Acceptable Alt: 370 to 740 km (>200 to 400 n.mi.)	Timing Accuracy: 1 millisec Aspect sensing

5.4.1 LOW ENERGY X-RAY TELESCOPE EXPERIMENTS (0.1 TO 5 keV)

5.4.1.1 Scientific and Technical Goals. The experiment objectives include measurement of selected sources at the same time that higher energy instruments in other experiments are utilized for observation in higher energy portions of the spectrum. Other objectives of the experiment may include:

a. Mapping of the background at a range of galactic latitudes, with an angular resolution of 2.9×10^{-4} rad (1 arcmin) or better in the wavelength regions 2×10^{-9} to 4×10^{-9} m (20 to 40 Å) and greater than 4×10^{-9} m (40 Å).

b. Survey of sources at 2×10^{-9} to 10^{-8} m (20 to 100 Å) at high galactic latitudes.

c. Maps of strong extended X-ray sources in the wavelength region 2×10^{-9} to 10^{-8} m (20 to 100 Å).

d. Spectral studies of sources with the object of determining the X-ray emission mechanism and attempts to detect absorption edges due to interstellar absorption, in the 2×10^{-9} to 10^{-7} m (20 to 100 Å) wavelength region. A by-product of this will be a determination of the interstellar cutoff as a function of distance and direction of the sources.

e. Time resolution measurements for the observation of irregular fluctuations, accretion phenomena and regular fluctuations associated with old pulsars.

f. Spectral studies of selected nearby stars to attempt to detect the presence and characteristics of their coronas.

5.4.1.2 Description. With the aid of an aspect sensor optical telescope, the field of view of the X-ray telescope is monitored in the visible and UV spectrum to obtain data for stabilizing X-ray imaging as well as to locate X-ray sources by interpolation. Together with the supporting vehicle offset star trackers the fixed mounted sensors of the high energy will be directed toward any selected set of coordinates with a precision of 5×10^{-6} rad (1 arcsec) and an absolute accuracy of 2.9×10^{-4} rad (1 arcmin) or better.

5.4.1.2.1 Imaging Detection and Transmission Grating Spectrometry. The experiment obtains intermediate resolution images of low energy sources for correlation with high energy phenomena measured from these sources. The high resolution images are obtained by focusing the X-rays upon an X-ray sensitive multichannel plate image intensifier and recording the resulting visual image with secondary emission imaging camera tube. Low resolution spectral data are also obtained by introducing a transmission grating in front of or behind the X-ray mirror. Each point in the field of view results in a point on a line image in which the position along the line follows the normal grating function of wavelength. The spectral resolution is poorer than obtainable with the Bragg spectrometer discussed in the next experiment, but data can be obtained more quickly over the entire spectral range which enables investigation of weaker sources and time variant behavior of strong sources.

Signals from the aspect sensor may be used to stabilize the resulting X-ray image in the intensifier section or at the imaging camera tube.

5.4.1.2.2 Spectrometry (8 to 20 Å, 1 keV to 6 keV). A Bragg type spectrometer is used at the focus of the Wolter X-ray telescope which is directed to a desired X-ray source by the supporting vehicle and an aspect detection device supporting the total experiment group.

Bragg crystal spectrometers have been built and flown on the OSO program by the GSFC group and the instrumentation has revealed a wealth of line structure in the 8 to 10 Å region. Much valuable information on the time variation of the lines during flares and during various phases of solar activity has been obtained. As rays from the source are essentially parallel when they reach the instrument, the plane crystal geometry may be used. The radiation from the source is allowed to strike the crystal, usually without any fore-optics or collimation, and the spectrum is scanned by rotating the crystal while simultaneously moving a detector through twice the angle through which the crystal moves. For stellar work, similar units may be used but with an X-ray telescope. In this manner the relation angle of incidence = Bragg angle = angle of diffraction may be satisfied for all incident wavelengths. Table 5-7 lists crystals that have been successfully used for solar soft X-ray spectroscopy, together with the 2d lattice spacing, which determines the wavelength range that can be covered by the crystal through the Bragg relation: $n\lambda = 2d \sin \theta$.

Table 5-7. Crystals Used for Solar X-ray Spectroscopy and Possibly Applicable for Stellar Work

CRYSTAL	2d	USED BY
Muscovite mica	19.8	Leicester
Potassium acid phthalate (KAP)	26.6	GSFC, NRL, Leicester, Aerospace
Octadecyl hydrogen maleate (OHM)	63.5	GSFC
Beryl	15.94	Leicester
Fatty acid multilayers, e.g., barium copper stearate (BCS)	Variable - depends upon particular fatty acid used and means of making multilayers. BCS gives 9.6×10^{-9} m (96 Å)	Los Alamos
Madagascar green prochlovite	27.6	Y. Cauchois (1962)

The choice between the various crystals will be made on the basis of resolving power, efficiency and mechanical properties, as we shall discuss below.

The plane crystal geometry cannot be directly used with the telescope, as the rays from a point image formed by the telescope diverge in a cone whose included angle is about 24°.

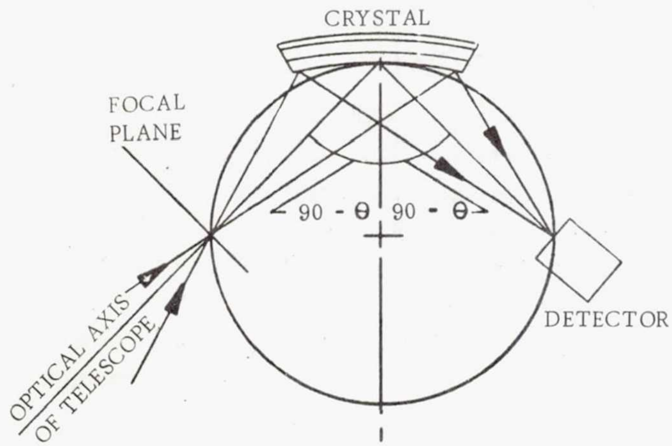


Figure 5-13. Curved Crystal Spectrometer

One method of using a divergent beam from a point source to feed a Bragg crystal spectrometer is to adopt the Johann curved crystal geometry. The method of doing this is shown in Figure 5-13. The image of the object under examination, the crystal, and the detector are all arranged to lie on the circumference of a circle (the Rowland circle), and the lines joining the center of the crystal to the source and to the detector, respectively, are arranged to make equal angles with the normal to the crystal. In order to scan in wavelength, this angle must be varied, while the components remain on the Rowland circle. Since the line joining the source to the center of the crystal must remain fixed, a linkage must be devised to maintain the correct relationships.

Two arms A_1 and A_2 are the same length, which is the length of radius R of the Rowland circle. The third arm, A_3, is of variable length. It slides in a hole in the crystal mount, which pivots on the crystal carriage. A_3 keeps the normal to the crystal passing through the (moving) center of the Rowland circle, which is at the junction of A_1, A_2 and A_3. A passive gearbox maintains the angles of incidence and diffraction equal.

A lazy-tongs device is used to point the detector at the center of the crystal, and need not be precisely constructed. The whole mechanism is actuated by translating the crystal along the optical axis by means of a leadscrew. This drive is not a linear wavelength drive but its calibration poses no particular problem.

To change the wavelength region of interest, several crystals are mounted on a turret which, when actuated by a rotary solenoid, brings different crystals into the beam. The selected telescope would employ OHM, stearates, and KAP. A possible problem area lies in the bending of the soft crystals such as KAP and OHM and some research in this area would have to be performed. The resolution, $R = \lambda/A$, obtainable with these crystals varies from around 1500 (KAP at $\sim 1.3 \times 10^{-9}$ m) to 100 - 200 (Stearates at $> 4.4 \times 10^{-9}$ m). This resolution is perfectly adequate for the study of the discrete sources. It exceeds by a large factor the resolution obtainable with proportional counters, which hitherto has been the only means for spectral discrimination in the longer wavelength region. Magnetic electron multipliers, "Channeltron" or "Funneltron" devices, will be used as detectors for the crystal spectrometers. The choice of

detector will depend on the outcome of work now in progress at GSFC and UCL on the lifetime of these detectors in space conditions. So far, recent experience with channel type detectors on the OSO-G UCL experiment has been quite encouraging.

5.4.1.3 <u>Observation/Measurement Program</u>. The basis for determining the observation measurement cycle for the Wolter telescope and its instruments is given in the following paragraphs. For the high resolution focus position of the telescope, an estimate is made of the magnitude of the faintest sources which can be seen with this detector. These will be seen when one of the low background counters is used. We assume first that we require the position of the source to no better than the field of view determined by the size of the detector window -- let this be 5.8×10^{-4} rad (2 arcmin). With the techniques of background discrimination that we propose to use, we expect a charged particle count rate of about 10^{-3} counts/second. The observing time per orbit will be about 5000 seconds giving 5 background counts/orbit. We assume that we need a 5σ signal to know, with absolute confidence, that a source is present. This means that our signal count must be at least 10 counts per orbit. Assuming a collecting area of 100 cm^2 and a combined reflection and detection efficiency of 0.1, we obtain the minimum detectable flux F as follows:

$$F = \frac{\text{required signal count}}{\text{Area} \times \text{Efficiency} \times \text{Seconds in an orbit}}$$

$$= \frac{10}{100 \times 0.1 \times 5000} = 2 \times 10^{-4} \text{ photons/cm}^2\text{/sec}$$

If the spacecraft is able to remain pointed at the same region accurately for a day, the limiting flux is reduced (by a factor of about 16) to 4×10^{-6} photons/cm^2/sec. The use of integration times of one day or longer will depend critically on the pointing and acquisition performance of the spacecraft.

NOTE

> The resultant observation time adopted is from 0.833 hours (50 minutes) to 24 hours; the 24-hour dwelltime on source should be scheduled for that time of year when earth position in orbit around the sun is such that the plane of the orbit of the vehicle carrying the telescope is roughly perpendicular to the direction of the source.

The observation measurement program for the low-energy X-ray telescope experiments is outlined below, including preparation and maintenance activities as well as normal operations. The typical observation/measurement cycle conducted simultaneously with all the high-energy stellar instruments is accomplished for each new source located. New sources are sought continually except for a brief period each 24 hours for remotely controlled checkout, alignment, and calibration.

The recommended preparation and observation cycle is as follows:

Ops	Task	Duration (hr/cycle)	Number of Cycles
Px	Initial Setup in Space (2 men)	4	1
P_{ac}	Remotely Controlled Alignment and calibration (1 man)	0.7	1 per 48 hours
	Observation Cycle		
a.	Observation Area Selection (& slewing)	0.2	Per source
b.	Reference or Guide Stars Acquisition	0.1	Per source
c.	Source Observation/Measurement	0.833 to 24	Per source
	Total per source	1.03 to 24.2	
	Repeat for next selected source		Continually
	Maintenance		
	Scheduled Service & Maintenance	4	1 per 6 months
	Unscheduled Maintenance	3	1 per year

5.4.1.4 X-Ray Telescope Experiments Interface, Support, and Performance Requirements. The interface, support, and performance requirements for the X-ray telescope experiments to be used in correlated operations with the high-energy stellar astronomy sensors are presented in Table 5-9 in Section 5.5. The table includes generalized alignment/calibration and reference or guide star acquisition operations required to prepare, orient, and enable stabilization of the associated experiment group.

5.4.1.5 Potential Role of Man. Man will periodically (at 6 month intervals) maintain, service, align, and calibrate the low energy X-ray experiment equipment better than can be accomplished by remote control. As new experiments become available for the X-ray telescope man will add or substitute them for the previous experiments.

During operation, particularly of the focused experiments, a ground based high-energy stellar astronomy observational team will monitor and control the X-ray telescope experiments as well as associated experiments.

5.4.1.6 Available Background Data. Information for the X-ray telescope experiments associated with high-energy stellar astronomy observations was obtained from the following sources.

a. September, 1969, edition of Blue Book, Section 5.1 and 5.5.

b. High-Energy Astronomy Payload Concept for Earth-Orbital Operation, SMSD-SSL-195, edited by J. M. Duffie, Brown Engineering Co., August, 1968.

5.4.2 X-RAY SOURCE MAPPING

5.4.2.1 Scientific or Technical Objectives. The experiment equipment will be able to map the diffuse X-ray radiation in two energy ranges on a scale of $0.1° \times 4°$ with an accuracy of ten percent. The map will provide the data needed to construct a total picture of all the phenomena involved; the extragalactic source with inverse-Compton, unresolved discrete sources, and intergalactic plasma components, interstellar absorption with cloud structure and elemental abundances; and contributions from local unresolved sources. Clearly, angular resolution is crucial to obtain valid data. No instrument with much more than a 0.1 square degree field of view for a resolution element can do this at present.

5.4.2.2 Description. The experiment will utilize the Venetian blind telescope described in Section 5.2.2 as well as a proportional counter detector assembly. An aspect sensor is desired for optical correlation of the X-ray and associated higher energy experiment observation with visible light sources where possible.

5.4.2.3 Observation/Measurement Program. The following operations and observation cycle are recommended:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial Setup (1 man)	4	1
	Observation/Measurement Cycle		
a.	Periodic Alignment and Calibration by Remote Control	0.5	1 per 48 hours
b.	Guide Star or Ref. Star Acquisition	0.1	per scan or per source
c.	Observation Object Acquisition	0.1 to 0.7	per source
d.	Observation of Selected Source	0.83 to 24	per source
e.	Repeat d if continuing to view same source.	0.83 to 24.7	same source

Ops	Task	Duration (hr/cycle)	Number of Cycles
f.	Repeat b, c, d, e if viewing next selected source.	1.03 to 24.7	per next source
–	Maintenance		
	Scheduled Service & Repair	4	1 per 6 months
	Unscheduled Maintenance	2	1 per year

5.4.2.4 Interface, Support, and Performance Requirements. For the X-ray source mapping experiment, interface, support, and performance requirements are given in Table 5-9 in Section 5.5.

5.4.2.5 Potential Role of Man. Man will periodically (at 6 month intervals) inspect, maintain, service, and align the Venetian blind telescope and its detector package. During operation, an observer at the ground-based monitoring and control point or in a space station will monitor the output results and will, by remote control, trim or adjust instrument operating parameters.

5.4.2.6 Available Background Data

a. Philip C. Fisher, et al, Proposal for a HEAO X-Ray Survey Experiment, 22 May 1970, Lockheed Palo Alto Laboratory, Lockheed Missiles and Space Company, Dept. 52-14, Bldg 202, Palo Alto, Calif.

b. Addendum I (to above), 10 Sept 1970.

5.4.3 NARROW BAND SPECTROMETRY AND POLARIMETRY (6 TO 10 keV)

5.4.3.1 Scientific or Technical Objectives. Simultaneous narrow band X-ray spectrometry and polarimetry measurements over the 6 to 10 keV interval will define X-ray continuum spectra and linear polarization with high precision and will determine selected line intensities if such exist. Line intensities and widths from various states of the same element and continuum polarization determinations will elucidate (1) state parameters such as temperature and relative elemental abundances; and (2) physical processes that give rise to the continuum and the lines. Source mechanisms for X-ray objects are still hazy. Yet, data distinguishing these mechanisms comprise fundamental information.

Line intensities from different elements will provide direct determination of relative abundances. Nucleosynthesis is thought to have recently occurred in some X-ray objects. Therefore, abundance measurements on iron group elements will be of extreme importance to questions of cosmic nucleogenesis of heavy elements.

X-ray lines at wavelengths in the 6 to 10 keV region are readily produced by transitions in very highly ionized states of iron and other nearby elements in the periodic table. As Tucker (1967) and Tucker and Gould (1966) have shown, an optically thin plasma with temperatures of 10^7 to 10^8 °K can produce strong emission lines (as well as a significant X-ray continuum) if the abundances and temperatures are appropriate. A majority of the known X-ray sources have spectra which look like thermal bremsstrahlung, and thus may be considered reasonable candidate objects for line measurements.

5.4.3.2 Description. Simultaneous, high resolution, spectrometric (E/ E = 350 or 60) and polarimetric X-ray observations are proposed to be accomplished in nine selected bands in the 6 to 10 keV range with the facility equipment described in Section 5.2.3.

a. Spectral Measurements. Energy bands are chosen to insure maximum likelihood of obtaining highly significant physical and cosmological insight into a wide variety of celestial objects. The energy band and bandwidth selections have been determined by theoretical and experimental considerations. Two assured continuum locations and seven line emission locations were selected. In sources not characterized by line emission, the simultaneous observation of intensity and polarization in all channels promises accurate continuum temperature determination, and a highly precise polarization measurement capability.

   Table 5-8 lists the nine observational bands selected for inclusion in the present experiment. Determination of the number of wavelength bands (nine) was based on the anticipated spacecraft dimensions and an assumed instrument location. It is certainly recognized that some alternate location may be necessitated by payload integration considerations and thus the experiment admits of some flexibility.

   The following considerations were used for preliminary selection of bands desired to be observed. These criteria are expected to be employed in the final allocation of spectrometer energies and bandwidths. First, there are several X-ray emission lines in the 5 to 10 keV energy range which have singular cosmological significance. In addition, the 5 to 10 keV band is well suited to the crystal diffraction X-ray telescopes described herein. For photon energies less than 5 keV, other techniques may be employed to conduct high resolution spectrometry; above ~15 keV other techniques, illustrated in other sections of this report, may be employed.

   Each band has been chosen carefully with respect to the importance of the desired information as well as feasibility of successful observations. The continuum locations, carefully selected for freedom from emission line or continuum edge contamination are essential for continuum polarization detection and allow a determination of free-free emission temperature.

   Bands 3 and 4 are anticipated to include the strongest lines in the spectral region, corresponding to Fe^{+24} and Fe^{+25}. Their detection would constitute virtually

Table 5-8. Observational Bands

Band	Feature	Energy (keV)	Bandwidth (eV)	Priority Order*
1	Continuum I	6.00	120	1
2	Continuum II	8.31	120	1
3	Fe^{+25}	6.64	20	1
4	Fe^{+25}	6.89	20	1
5	Ni^{+27}	7.99	20	3
6	Fe^{+25}	6.89	120	4
7	Fe^{+24}	6.64	120	4
8	Co^{+26}	7.43	120	5
9	Fe^{+25}	8.17	20	6
**	Si^{+12}	1.87		2
**	Si^{+13}	2.00		2

* An indication of rank but no indication of absolute priority is intended.

** Deferred due to larger size, which increases experiment cost as well as requiring greater volume.

conclusive evidence for a thermal mechanism, and their relative strength would yield an ionization temperature. Wide band (120 eV) collectors have been assigned to the continuum bands and narrow band (20 eV) collectors to the Fe line locations to insure the best statistics. Doppler shifts and Doppler broadening will not occasion loss of emission line photons outside of the narrow bands or contamination of the continuum locations in the majority of anticipated X-ray objects.

A narrow-band monitor of Ni^{+27} if provided in band 5. Nickel is chosen because of its high cosmic abundance and membership in the iron peak group. Fe/Ni ratios may be determined with the data from bands 1 through 5.

Bands 6 through 8 are designed to accommodate sources characterized by larger Doppler shifts or Doppler broadening. Supernovae remnants will fall into this category. The same logic as before motivates observation in the two iron lines, bands 6 and 7. From these data an ionization temperature may be determined which is required to obtain relative elemental abundances.

Band 8 enables a wideband observation of a predicted ^{56}Co line. This band is specifically intended for a supernova experiment to (a) observe the transition of ^{56}Ni through ^{56}Co to ^{56}Fe and (b) measure the X-ray opacity (probably time

varying) of the supernova shell. Such an X-ray measurement, if combined with gamma ray observations of the radioactive decay of these elements, would give deep insight into the physical conditions within the shell – even if the cobalt X-ray line proves to be undetectable. Furthermore, band 8 provides an additional continuum and polarization channel for nonsupernova observations.

Band 9 enables observation of the Fe^{+25} (1s-3p) transition and, if found, would lend definitive confirmation to the Fe identification as well as semi-independent ionization temperature determinations when combined with bands 3 and 4.

Table 5-8 also shows two silicon lines. Observation of the Si lines would be of considerable cosmological significance and would enable temperature determination in cooler sources than the iron lines will permit; thus spectrometric capability at these energies (≈ 2 keV) by space experiment would be very desirable. Such a measurement could and should be accomplished with the crystal diffraction techniques being proposed. Indeed, strong arguments can be brought forward to justify its inclusion in the present experiment:

1. The time variability of some known X-ray sources could make the crucial Fe and Si comparison less significant if the two lines are not observed simultaneously.

2. Dual observation of data of such high significance by two different experimental techniques is always desirable.

However, the measurement of silicon has been omitted from the proposed experiment to insure a minimum of scientific duplication and a maximum of correlated information return from a number of diversified instruments.

b. Polarization Measurements. It is well known that sources which radiate by synchrotron radiation should be polarized if there is any systematic configuration to the magnetic field. Of course if the field is completely chaotic (spaghetti field) the polarization of the whole system may well be very small. Thermal sources would not be expected to be substantially polarized unless the plasma exhibits spherical asymmetry and is slightly optically thick (Angel et al., 1969).

The proposed experiment will be able to measure polarization in all energy bands by means of sectored detectors (see Section 5.2.3.3 for instrumentation detail) over the interval from 6 to 10 keV. For partially polarized sources, the polarization data will assist in separating line radiation from continuum radiation. Line radiation is not expected to be polarized.

The Crab Nebula is a strong nearby source, the spectrum of which suggests synchrotron radiation as the X-ray production mechanism. Therefore, it is a prime candidate for high-precision X-ray polarization measurements. To illustrate the accuracy of polarimetry possible with the proposed instrument, the expected standard deviation σ_p in the degree of linear polarization of the Crab is estimated here on the basis of equation 37 of Appendix B.

If a representative value of 4 is adopted for K, a Bragg-angle-dependent quantity, then

$$\sigma_p = 4/(2N)^{1/2}$$

where N is the total number of counts received by any one of the nine X-ray units. The measured differential flux of photons from the Crab is about 0.5 cm^{-2} sec^{-1} keV^{-1} at 6 keV. In a 30-minute observation, the total numbers of counts detected by cones of 500 cm^2 effective area and bandwidths, respectively, of 20 eV and 120 eV will be,

$$N_{20} = (0.5\ cm^{-2}\ sec^{-1}\ keV^{-1})\ (500\ cm^2)\ (1800\ sec)\ (0.02\,keV) = 9000\ photons$$

and

$$N_{120} = 6\ N_{20} = 54000\ photons$$

Hence, in terms of percentage, the experimental standard deviations in degree of linear polarization will be

$$\sigma_p = 2.5\%\ \text{for a 20 eV polarimeter channel}$$

$$\sigma_p = 1.2\%\ \text{for a 120 eV polarimeter channel}$$

Very useful determinations of polarization to test the synchrotron radiation mechanism are, therefore, possible. The polarimetric precision can be further improved for a continuum source whose degree of polarization does not change significantly over the 6 to 10 keV range. The Crab and, in general, synchrotron sources are expected to fall in this category. To accomplish this improvement the data from all the cones is combined by addition of identically oriented sectors which will provide a statistical error reduction proportional to the square root of the total number of polarimeter channels; a factor of 3 in the present instrument.

5.4.3.3 Observation/Measurement Program. The observation/measurement cycle will parallel that for the associated experiments, all operating at the same time in different portions of the spectrum on the same source. Although the asymmetric cone spectrometer/polarimeter units can obtain data on some sources in 1800 seconds, the average observation time for all experiments of a pointed high-energy stellar observatory vehicle will be longer per source. The following predicted operations and observation cycles are recommended:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial setup	9	1
O/M	Observation/Measurement Cycle		
a.	Periodic check and calibration	0.5	1 per 48 hours
b.	Guide or ref star acquisition (by associated aspect sensor)	0.1	1 per source
c.	Observation scanning or acquisition	0.1 to 0.7	per source
d.	Observation of selected source	0.83 to 24	per source
e.	Repeat d if continuing to view same source for time variant phenomena	0.83 to 24	per source
f.	Repeat b, c, d, if viewing next selected source	1.03 to 24.7	per next source
M	Maintenance		
	Scheduled service and repair	4	1 per 6 month
	Unscheduled maintenance	2	1 per year

5.4.3.4 Narrow Band (6 to 10 keV) Spectrometry and Polarimetry Interface, Support, and Performance Requirements. Interface, support, and performance requirements for the 6 to 10 keV narrow band spectrometry and polarization measurements experimented are summarized in Table 5-9. In addition, each asymmetric spectrometer/polarimeter unit needs to be aligned to the reference axis of the pointed group of instruments to better than 2.9×10^{-4} rad (1 arcmin). The units can be mounted so that their apertures are in the same plane as the other instruments to minimize shadowing or interference problems.

5.4.3.5 Potential Role of Man. The potential role of man in the multiple unit narrow band spectrometer/polarimeter experiment is information-processing planning, initial checkout, periodic inspection and calibration, and occasional replacement of detector assemblies and electronics submodules. Man is expected to be useful in exchanging units with other preadjusted units as additional spectral lines need to be investigated. By remote control, man will, of course, periodically monitor and control (trim adjustments) of the experiment units to optimize experiment return. An observation team at an experiment control center on earth will plan and prepare computer routines for combining data from the individual spectrometer/polarimeter units and from associated experiments to enable efficient acquisition of information about the radiation source mechanisms.

5.4.3.6 Available Background Data.

a. R. Graham Bingham, et al, Flight Instrument Proposal for a Multichannel, Asymmetric - Bragg Crystal, X-ray Spectrometer and Polarimeter for the HEAO Spacecraft, The Boeing Company, 27 May 1970.

b. Matsuoka, Masaru, Distribution of X-ray Sources and Appearance Frequency of Galactic X-ray Stars, Institute of Space and Aeronautical Science, University of Tokyo, Report No. 445, 1970.

5.4.4 LARGE AREA X-RAY COUNTER MEASUREMENTS (0.1 TO 100 keV)

5.4.4.1 Scientific or Technical Objectives. The objectives of the X-ray counter measurements are to obtain the celestial coordinates and spectral intensities of sources in the 0.1 to 100 keV range at the same time focused X-ray instruments and higher energy sensors are obtaining data.

Scientific objectives include acquisition of information on the following extragalactic objects or phenomena:

a. Correlation of quasars and strong radio sources with X-ray emitters

b. Correlation of radio quiet galaxies with strong X-ray sources

c. X-ray luminosity and spectral characteristics of Seyfort galaxies

d. X-ray spectral intensities of M-31/M-33 normal type galaxies

e. Absorption characteristics of intergalactic space, particularly in the 2×10^{-9} m (20 Å) and 5×10^{-9} m (50 Å) regions

f. Source of diffuse X-ray background

g. Distribution of equivalent brightness versus red shift

h. Variability of X-ray galaxies such as M87, 3C273, including source size and physical processes clues

i. Spatial distribution from Cen A, including indications of degree of compatibility of distribution with Compton inverse emission from 3°K cosmological background radiation.

Information desired from studies of sources in our own galaxy will be of a somewhat different nature. Because of greater equivalent brightness of local sources, searches for specific line emission becomes feasible. Precise positioning using modulator collimator response should lead to better correlation with optical results thus far on all sources detected. Since previous observations will have been fairly well completed, most of the observations will consist of longer dwell time measurement of characteristics of previously located sources although some search for new sources is possible.

Information needed about X-ray sources in our own galaxy include:

a. Correlation of X-ray sources with optically detectable objects

b. Potential of bremmstrahlung contribution to emission process of sources such as Sco XR-1, Crab Nebula, Crab pulsar, Cyg XR-2, Cos A

c. Possibility of X-ray pulsar in Cos A or Cyg XR-1

d. Detectability of flare stars, magnetic stars, planetaries, WR stars, M or K stars, etc., as X-ray sources

e. Existence of class of hard X-ray objects detectable at photon energies of 15 to 100 keV but not detectable at 1 to 10 keV

f. Absorption between earth and various X-ray sources, including clues on source of absorption and equivalent column density.

5.4.4.2 Description. The experiment will be conducted with the large X-ray counter array and associated equipment described in Section 5.2.4. Observations will be made, using equipment and described in Section 5.2.4 in the 0.1 to 100 keV range, at the same time as observations are made on a source at lower and higher energies. Although the field of view of the associated instruments point in the same direction and will normally be used to obtain detailed information on already discovered sources, some search capability will be retained.

5.4.4.3 Observation/Measurement Program. The observation/measurement cycle will parallel that of the associated experiments, all operating at the same time in different portions of the spectrum on the same source. The predicted operations and observation cycles are described as follows:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial Setup (2 men)	4	1
	Observation/Measurement Cycle		
a.	Periodic Alignment & Calibration	0.5	1 per 48 hours
b.	Guide Star or Ref. Star Acquisition	0.1	1 per source
c.	Observation Area Scanning or Acquisition	0.1 to 0.7	1 per source
d.	Observation of Selected Source	0.83 to 24	per source
e.	Repeat d if continuing to view same source.	0.83 to 24	per source
f.	Repeat b, c, d, e if viewing next selected source.	1.03 to 24.7	per next source

Ops	Task	Duration (hr/cycle)	Number of Cycles
M	Maintenance		
	Scheduled Service & Repair (2 men)	4	1 per 6 month
	Unscheduled Maintenance	2	1 per year

5.4.4.4 Interface, Support, and Performance Requirements. Interface, support, and performance requirements estimates are given in Table 5-10 in Section 5.5.

5.4.4.5 Potential Role of Man. The potential role of man in the large area X-ray counter measurements experiment is initial setup, checkout, and periodic alignment and calibration of the equipment (probably at 6 month intervals). Man also is useful in updating modular sections of the experiment equipment as better component units are developed and built. Manned monitoring and (trimming) control of the experiment units will be accomplished periodically to enable cross correlation with other experiment results.

5.4.4.6 Available Background Data

H. Friedman, A Proposal to Fly X-Ray Counters and Associated Hardware, E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D. C.

5.4.5 COSMIC X-RAY ENERGY SPECTRA (6 TO 400 keV)

5.4.5.1 Scientific and Technical Objectives. The purpose of this experiment is to obtain information for studies in X-ray astronomy by using a large area, low-background detection system whose photon energy range is 6 to 400 keV. The most important goal of the experiment is to obtain energy spectra with good resolution and with high statistical precision. Overlap with proportional counters on the low energy side and with gamma ray detectors on the high energy side is provided to allow normalization of flux data of sources over a very wide range.

The scientific goals of the experiment in the spectral region from 6 to 400 keV are:

a. Spectral information on known X-ray sources

b. Locations of additional X-ray sources

c. Variation of X-ray flux area time scale from milliseconds to hours

d. Characteristics of diffuse X-ray background over six month intervals

e. Information leading to identification of which or both of X-ray production mechanisms (i.e., thermal with exponential shape spectrum and synchrotron radiation

confirming to power law) causes X-rays in the 6 to 400 keV spectrum for each given source.

5.4.5.2 Description. The experiment will use four detector units to measure radiation from selected or located sources emitting radiations between 6 and 400 keV at the same time that lower and higher energy instruments are utilized. The detectors planned are designed to provide the best possible energy resolution in the 6 to 400 keV range combined with high sensitivity.

5.4.5.3 Observation/Measurement Program. To obtain better observation of a given source than previously possible in the spectrum from 6 to 400 keV, the low background detector array is pointed in the direction of the observed source for periods of time varying from 50 minutes to 24 hours. While a pointing accuracy of only about 4.3×10^{-3} rad (0.25°) with a stability of 4.4×10^{-5} rad (90 arcsec) per observation time is desired, the array will be pointed at the source with a greater accuracy and stability since the associated X-ray telescope will be also pointed at the same source at the same time.

The following operations and observations cycle is recommended for man-supported and man-controlled (remotely) experimental measurements:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial Setup	4	1 per flight
O/M	Observation/Measurement Cycle		
a.	Periodic Adjustment and Calibration by Remote Control	0.5	1 per 48 hours
b.	Guide or Reference Star Acquisition	0.1	per source
c.	Observation Object Acquisition	0.1 to 0.7	per source
d.	Observation of Selected Source	0.83 to 24	per source
e.	Repeat d, if continuing to view same source.	0.83 to 24	per source
f.	Repeat b, c, d, e if viewing next selected source	1.03 to 24.7	per next source
M	Maintenance		
	Scheduled Service and Repair	4	1 per 6 months
	Unscheduled Maintenance	2	1 per year

5.4.5.4 Cosmic X-Ray Energy Spectrometer (6 to 400 keV) Experiment Interface, Support and Performance Requirements. The interface, support and performance requirements for the cosmic X-ray energy spectra experiment are tabulated in Table 5-9 in Section 5.5.

5.4.5.5 Potential Role of Man. The potential role of man in cosmic X-ray energy spectra experiment support consists of initial checkout and calibration in space as well as periodic alignment calibration and repair. Continual remote monitoring and control will enable acquisition of data in the 6 to 400 keV spectrum to enable ready correlation with the associated experiments in the other portions of the high-energy spectrum.

5.4.5.6 Available Background Data

K. A. Anderson, L. E. Peterson, C. S. Bowyer, and M. L. Lampton, Energy Spectra of Cosmic X-Ray Sources, 6 to 400 keV, 27 May 1970.

5.4.6 GAMMA RAY SPECTROMETRY (0.06 TO 10 MeV)

5.4.6.1 Scientific or Technical Objectives. The scientific objectives of the gamma ray spectrometry experiments in the 0.06 to 10 MeV spectral region are:

a. Location, intensity, and detailed spectrum of X-ray and gamma ray sources with the emphasis on fine spectral details such as line structure

b. Information on time variations in intensity and spectral details of discrete X-ray and gamma ray sources

c. Information enabling study of origin, isotropy, and spectral details of the diffuse and gamma ray background.

Power law spectra have been noted in the Crab Nebula and Cygnus XR-1; an exponential spectrum has been found in Scorpius XR-1. Because of limitations in sensitivity, no spectrum has been measured greater than 0.5 MeV and no line features have ever been observed. Theory indicates that continuum gamma ray emissions in the range of 0.5 MeV to 10 MeV could be generated by extremely energetic electrons gyrating in magnetic fields, Compton scattering, or emitting bremmstrahlung in high density regions or very hot thermal gases, and that line emissions should result from many processes of nucleosynthesis. A high sensitivity instrument capable of measurements in this difficult region of the spectrum would provide new information on processes taking place in discrete and diffuse sources.

5.4.6.2 Description. A Ge(Li) crystal detector unit refrigerated by a solid cryogen refrigeration unit will be used to receive gamma rays through a clear conical field of view of 0.61 rad (35°) half angle (total FOV = 1.22 rad, or 70° with a response of

0.61 rad or 30° FWHM) in the spectral region from 0.06 MeV to 10 MeV. Aspect information will be supplied at the instant each event is measured to determine the direction of the source. Direction data for events need identification to enable correlation with results of other sensors pointed at a given source.

5.4.6.3 Observation/Measurement Program. The gamma ray spectrometry in the 0.06 to 10 MeV spectral region is accomplished at the same time as the X-ray telescope, Venetian blind telescope, and other associated high-energy experiments.

The operations and observation measurement cycles for the experiment are as follows:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial Setup (2 men)	4	1
O/M	Observation/Measurement Cycle		
a.	Periodic Adjustment & Calibration by Remote Control	0.5	1 per 48 hours
b.	Guide Star or Reference Star Acquisition	0.1	per source
c.	Observation Object Acquisition	0.1 to 0.7	per source
d.	Observation of Selected Source	0.83 to 24	per source
e.	Repeat d. if continuing to view same source.	0.83 to 24	per source
f.	Repeat b., c., d., e. if viewing next selected source.	1.03 to 24.7	per next source
M	Maintenance		
	Scheduled Service and Repair	4	1 per 6 months
	Unscheduled Maintenance	2	1 per year

5.4.6.4 Gamma Ray Spectrometry Experiment Interface, Support, and Performance Requirements. The interface, support, and performance requirements that may be standardized and compared to those of the other high-energy stellar astronomy experiments are tabulated in Table 5-9 in Section 5.5. In addition special interface, support, and performance requirements are discussed in the following paragraphs.

The detector assembly should be located away from large mass items to enable the detector to function correctly.

Aspect information needs to be furnished continually to at least 1.74×10^{-2} rad (1°) to be available at the time an event is registered. The instrument vector will be co-aligned with all other instruments aboard which are viewing X-ray and gamma sources.

Potential prelaunch servicing of the refrigeration unit requires that it will be accessible.

Photomultiplier tubes can be disrupted by magnetic fields; although shielding is provided in the detector assembly, fields stronger than 2 nT in the vicinity should be avoided.

Perceptible quantities of radiation sources on board the carrier spacecraft or in the construction materials can not be tolerated.

The gamma ray spectrometer should be kept away from large heat dissipators.

Passage through the South Atlantic anomaly will leave a residual dead time of about 50% which will drop to its nominal value after one hour. There is expected to be some activation of the Ge(Li) crystals, which will decay with an 80-minute half life. Orbital selection should enable avoidance of the South Atlantic anomaly as much as possible. If the spacecraft passes through the anomaly, currents to the photo multiplier tubes will be limited by special circuits to avoid damage.

Special materials with low Z should be used in the gamma ray detector vicinity to minimize secondary radiation caused by cosmic rays.

5.4.6.5 Potential Role of Man. Man will periodically (at 6-month intervals) inspect, maintain, service, align, and calibrate the gamma ray spectrometer equipment better than can be done by remote control. In between service periods, of course, remote control adjustments and monitoring will be accomplished to trim the equipment to maximum and appropriate performance for the sources observed. As new component parts became available for the gamma ray spectrometer, replaceable units will be updated or the whole detector unit will be exchanged in space to obtain higher spectral (energy level) accuracy and resolution. (Accumulative radioactivity of the detector unit crystals may also require exchange at two-year intervals.)

5.4.6.6 Available Background Data

A. S. Jacobson, J. R. Arnold, A. E. Metzger, L. E. Peterson, A High Resolution Gamma Ray Spectrometer for the 0.06 to 10 MeV Region, sponsored by JPL, CIT, Pasadena, California 91103, 18 May 1970

5.4.7 HIGH ENERGY GAMMA RAY MEASUREMENTS WITH A LARGE AREA SPARK CHAMBER

5.4.7.1 Scientific or Technical Objectives. The scientific objectives for the high-energy gamma ray measurements in the 10 MeV to 30 GeV range are as follows:

a. Precise location in direction of cosmic sources of gamma rays of flux greater than 1×10^{-7} photon cm^{-2} sec^{-1}

b. Measurement of flux of selected high-energy source gamma ray photon groups

c. Measurement of background (flux and isotropy) of photons and charged particles for regions of sky where no point sources of high energy are found

d. Correlation of gamma ray activity in the 10 MeV to 30 GeV spectral region with other portions of the high-energy spectrum that are measured at the same time.

5.4.7.2 Description. The high-energy gamma rays are detected via their production of electron-positron pairs (or Compton recoil electrons at the lowest energies) in the plates of a spark chamber. The spark chamber determines angular location of sources (over the diffuse background) to 1.74×10^{-3} rad (0.1°). Energy measurement is accomplished by a large CsI or NaI crystal or other energy absorption counter and by multiple scattering in the spark chamber. Time-of-flight discrimination in the scintillation counter triggering circuits enables minimizing of spurious pulsing of the spark chamber. Flexibility in the triggering modes allows variation of the acceptance cone of the spark chamber.

5.4.7.3 Observation/Measurement Program. The gamma ray measurements in the 10 MeV to 30 GeV spectral region are accomplished at the same time as are the other experiments of the high-energy stellar astronomy groups. The operations and observation/measurement cycles for the experiment are as follows:

Ops	Task	Duration (hr/cycle)	Number of Cycles
I_{su}	Initial Setup (2 men)	4	1
O/M	Observation/Measurement Cycle		
a.	Periodic Adjustment and Calibration	0.5	1 per 48 hours
b.	Guide Star of Reference Star Acquisition	0.1	per source
c.	Observation Object Acquisition	0.1 to 0.7	per source
d.	Observation of Selected Source	0.83 to 24	per source
e.	Repeat d., if continuing to view same source.	0.83 to 24	per source
f.	Repeat b., c., d., e. if viewing next selected source.	1.03 to 24.7	per next source

Ops	Task	Duration (hr/cycle)	Number of Cycles
—	Maintenance		
	Scheduled Service & Repair	4	1 per 6 months
	Unscheduled Maintenance	2	1 per year

5.4.7.4 High-Energy Gamma Ray Measurements Experiment Interface, Support, and Performance Requirements. The large area spark chamber experiment interface, support, and performance requirements are tabulated in Table 5-9 in Section 5.5 except for some special requirements which are discussed below.

The large area spark chamber equipment should be kept out of the high intensity regions of the Van Allen belts and of the South Atlantic Anomaly. When the spacecraft has to proceed through a high-flux, high-energy region, the equipment should be turned off. The CsI or NaI crystals are expected to become self-radioactive for a time upon passage through the anomaly.

The large area spark chamber should be installed near the outer end of the carrier supporting vehicle, away from large masses or high Z material. Geometric alignment of the large area spark chamber acceptance cone axis should be aligned to the aspect sensor and to each other experiment axis to 0.05° or better.

The spark chamber will cause interference to other instruments in the group only infrequently since one event per 1800 seconds is expected. During that time some of the low energy instruments will experience interference.

5.4.7.5 Potential Role of Man. Man will periodically (at six-month intervals) inspect, maintain, service, align, calibrate the large area spark chamber equipment better than can be done by remote control. In between service periods, of course, remote monitoring and control will be accomplished in order to trim equipment to maximum and appropriate performance for each source observed. As new component parts or improvements occur, man can retrofit or replace some items in space at about two-year intervals.

Remotely controlled checkout, monitoring, and experiment functions will be accomplished by astronomer/astrophysicist/observer personnel at the space experiment control center.

5.4.7.6 Available Background.

G. M. Frye, A. D. Zysh, V. D. Hopper, W. Rawlinson, and H. H. Heckman, High-Energy Gamma Ray Astronomy with a Large Area Spark Chamber, C/O Case Western Reserve University, Cleveland, Ohio 44106.

5.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

Table 5-9 presents the FPE level interface, support, and performance requirements. The last column in the table shows the combined and preferred requirements. If an alternative or minimum requirement is possible, the next to the last column shows it. Since the experiments operate simultaneously to give complete coverage from 0.1 keV to 30 GeV, the power levels and data outputs add. When the experiment carrying vehicle is serviced at about six-month intervals, only two people will probably fit into the experiment area at the same time, hence, an elapsed time of about 21.25 hours will be required if three shifts of personnel work continuously to check service, align, and calibrate the experiment equipment.

Since several of the experiments need aspect sensing to assist in identifying and locating the source, there will be need to transmit the visible (or UV) image of the region being observed to the monitoring and control position with a fairly good resolution. If an image per 10 seconds is sent, the average data rate over the 10 seconds is expected to be about 7×10^5 bits per second; if one image per second is transmitted, data rate would be 7×10^6 bits per second. The primary experiment output data is not expected to exceed 26,000 bits per second since some pre-processing is accomplished at each experiment package.

5.6 POTENTIAL MODE OF OPERATION

Since the experiments may be affected by the large mass of a space station, and particularly by a nuclear electric or radioisotope power source if one is used at the station, a free flying mode is recommended. Some of the X-ray experiments are also affected by contamination in the vicinity of the station. If the group of six experiments, each with its axis parallel to the axis of each of the other experiments, is to be attached to a space station for operations, gimballing of the whole experiment platform or module is recommended. Some observation/measurement may be possible from the space station if the power source of the station is non-nuclear and if the experiment containing module can be mounted at some outer end away from large mass and high Z material.

Applicability of the optional mission modes for operation of this FPE is as follows:

Mission A - Limited on Orbit Stay Time With Space Shuttle. This mission does not appear useful for this group of experiments as a package, however a few individual experiments (of modified design) might benefit from such a mission. The individual selection would have to be determined.

Mission B - Extended Orbit Stay Time Revisited by a Shuttle. This is the desired mode of operation for this FPE. The RAM/High-Energy Package will be launched by the Shuttle and checked out in orbit. If all the basic support systems and a majority of the experiments are operating satisfactorily, the package will be deployed for extended

Table 5-9. High Energy Stellar FPE Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	a. Alignment and Calibration	b. Reference or Guide Stars Acquisition	c. 5.4.1 Low Energy X-Ray Experiments (0.1 to 6 keV)	d. 5.4.2 X-Ray Source Mapping (1 to 20 keV)	e. 5.4.3 Narrow Band Spectrometry and Polarimetry (6 to 10 keV)	f. 5.4.4 X-Ray Measurements (0.1 to 100 keV)	g. 5.4.5 Cosmic X-Ray Energy Spectra (0.6 to 400 keV)	h. 5.4.6 Gamma Ray Spectrometry (0.06 to 10 MeV)	i. 5.4.7 High Energy Gamma Ray Measurement (10 MeV to 30 GeV)	MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	All Equipment Composite Alignment and Calibration	Guide Star Trackers Aspect Sensor	Wolter Type I Glancing Incidence X-Ray Telescope Aspect Sensor Bragg Crystal Spectrometer Imaging Detectors	Venetian Blind X-Ray Telescope Aspect Sensor X-Ray Proportional Counter Detector Assembly	Asymmetric Cone Spectrometer/Polarimeter Assys (9) Combining Unit Aspect Sensor	Large X-Ray Counter Array (Mapping Modules)	Low Background Detector Array with 6 to 400 keV Detector Units	High Resolution Gamma Ray Spectrometer with Ge(Li) Detector/Refrigeration Unit Aspect Sensor	Large Area Spark Chamber Aspect Sensor		
Launch Mass, kg (Weight, lb)	60	140	200 (440)	658 (1450)	272 (600)	225 (496.7)	264 (583)	200 (440)	1398 (3080)	3300 (7290)	3300 (7290)
Logistics Support											
Consumables, kg/180D (lb/180D)						48 (105)	10 (22)	20 (44)		78 (171)	78 (171)
Spares, kg/180D (lb/180D)	10 (22)	30 (66)	20 (44)	100 (220)	110 (88)	25 (55)				225 (495)	225 (495)
Crew Support											
Initial Setup, Manhours/180D	2	0.5	8	4	9	8	4	8	8	42.5	42.5
Periodic Serv. & Maint., Manhours/180D	2	0.5	4	4	8	4	4	4	4	26.5	26.5
Operation, Remote Control, Manhours/Observation Cycle	1 per 48* hours	0.2 to 0.8 for acquisition (all exps. at same time)	0.83 to 24**	0.83 to 24**	0.83 to 24**	0.83 to 24**	0.83 to 24**	0.83 to 24**	0.83 to 24**	1.03 to 24.8**	1.03 to 24.8**
Electric Power:											
Peak Load, Watts	30	21	100	90	50	100	11	30	50	401	435
Average Load, Watts	20	18	50	60	50	23	10	20	48	213	231
Standby Load, Watts	20	18	50	60	50	23	10	20	48	193	211
Environmental Control											
Desired Vehicle Heat Sink Temp, °K											
Temp. Limits, Stowed, °K	283 to 298	253 to 309	263 to 303	263 to 293	253 to 293	263 to 293	263 to 298	253 to 323	253 to 323	263 to 293	263 to 293
Temp. Range, Ops., °K	288 to 293	273 to 300	273 to 293	272 to 274	253 to 293	272 to 274	288 to 293	273 to 303	263 to 303	288 to 290	272 to 274
Max. Temp. Difference, °K	2	2	2	2	2	2	2	2	2	2	2
Relative Humidity, %	< 40	<40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	< 40	<40
Atmosphere Limit, N/m^2 (psi)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	1.33×10^{-4} (10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)	0 to 10^5, 1.33×10^{-4} (0 to 15, 10^{-6} torr)		0 to 10^5 (0 to 15)	1.33×10^{-4} (10^{-6} torr)
Cleanliness Class	10,000	100,000	Pref: 10,000 Max: 100,000	10,000	10,000	100,000	—	—	—	100,000	10,000
Gravity Level, Max. g	$<10^{-3}$	$<10^{-3}$	10^{-4} operating	defl within tolerance	10^{-4} operating	—	—	—	—	10^{-3}	10^{-4} operating
Radiation Sensitivity, millirad/hr	<1	<1	<1	< 1	< 1***	<1	<1	< 1***	< 1	To give minimum self radioactivity	<1
Contamination Sensitivity	moderate	slight	moderate	moderate	moderate	moderate	slight	slight	slight	slight to moderate	moderate

* Six experiment calibrations accomplished at the same time to minimize downtime; may require 2 men to monitor experiments.
** May require 3 shifts at ground-based monitoring and control point (1 man may be able to monitor instruments, but requires periodic relief).
*** Nonoperative in South Atlantic Anomaly.

Table 5-9. High Energy Stellar FPE Interface, Support, and Performance Requirements, Contd

	a.	b.	c.	d.	e.	f.	g.	h.	i.		
EXPERIMENT / INTERFACE OR SUPPORT PARAMETERS	Alignment and Calibration	Reference or Guide Stars Acquisition	5.4.1 Low Energy X-Ray Experiments (0.1 to 6 keV)	5.4.2 X-Ray Source Mapping (1 to 20 keV)	5.4.3 Narrow Band Spectrometry and Polarimetry (6 to 10 keV)	5.4.4 X-Ray Measurements (0.1 to 100 keV)	5.4.5 Cosmic X-Ray Energy Spectra (0.6 to 400 keV)	5.4.6 Gamma Ray Spectrometry (0.06 to 10 MeV)	5.4.7 High Energy Gamma Ray Measurement (10 MeV to 30 GeV)	MINIMUM ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:											
Desired Inclination, deg			0	0	0	0	0 *	0 *	0*	—	0 *
Acceptable Inclination, deg	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	55 to 0	—
Desired Altitude, km (n.mi.)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)	740 to 930 (400 to 500)		740 to 930 (400 to 500)
Acceptable Altitude, km (n.mi.)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	370 to 740 (200 to 400)	—
Orientation:											
Observed Object Location	Selected reference source of radiation	Cataloged ref. or guide stars	Galactic, extra-galactic sources	Galactic and extra-galactic sources	Galactic and extra-galactic sources	Parallel with x-ray telescope	Galactic or extra-galactic sources	Galactic or extra-galactic sources	Galactic or Extra-galactic sources	Galactic or extra-galactic sources	Galactic or extra-galactic sources
Observed Object Brightness, mag, m_v (photons/cm^2/sec)		~2.5 to 8	(>6×10^{-5})	Sco XR-1 to 10^{-4} Sco XR-1	Sco XR-1 to 10^{-4} Sco XR-1	Sco XR-1 to 10^{-4} Sco XR-1	—	—	—	(6.5×10^{-5}) to Sco XR-1	(6.5×10^{-5}) to Sco XR-1
Observation Field of View	2.64×10^{-2}, 4.3×10^{-3}, 5.82×10^{-3} rad (90, 15, 20 arcmin)	Max: 2.64×10^{-2} rad (90 arcmin) Des: 4.35×10^{-3} rad (15 arcmin)	1.75×10^{-3} to 7×10^{-2} rad (0.1 to 4°)		≤1.75×10^{-2} rad (60 arcmin)	1.05×10^{-2} rad (36 arcmin)	2.64×10^{-2} rad (90 arcmin)	0.53 rad (30°)	0.17 to 0.017 rad (10 to 1°)	5.82×10^{-4} to 0.53 rad (2 to 1800 arcmin)	5.82×10^{-4} to 0.53 rad (2 to 1800 arcmin)
Pointing Accuracy, rad (arcsec)	9.7×10^{-6} (2)	9.7×10^{-6} to 2.9×10^{-4} (2 to 60)	9.7×10^{-6}; 6.8×10^{-5} Pref: (2); Acc: (15)	1.7×10^{-3} (360)	1.45×10^{-3} (<300)	1.7×10^{-3} (360)	4.4×10^{-3} (900)	0.017 (3600) (aspect info)	1.7×10^{-3} (360)	5×10^{-6} to 2.9×10^{-4} (2 to 60)	5×10^{-6} (2)
Pointing Stability, rad/obs time (arcsec/obs time)	5×10^{-6} (1)	5×10^{-6} (1)	5×10^{-6} (~1)	2.8×10^{-4} (<60)	2.8×10^{-4} (<60)	2.8×10^{-4} (<60)	4.4×10^{-4} (<90)	1.7×10^{-3} (360)	2.8×10^{-4} (60)	5×10^{-6} to 1.7×10^{-3} (1 to 360)	5×10^{-6} (1)
Slew Rate, max., rad/sec (arcsec/sec)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)	1.7×10^{-3} (360)
Slew Rate, min., rad/sec (arcsec/sec)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)
Pointing Hold Time, sec	2520	360	3000 to 86,400	3000 to 86,400	1800 to 86,400	3000 to 86,400	300 to 86,400	3000 to 86,400	3000 to 86,400	3000 to 86,400	3000 to 86,400
Data Requirements/Observation Cycle:											
Spectral Range											
Imaging Data											
Desired Resolution (spatial or spectral)	same as a thru i	For 900 arcsec field angular Min: 2.9×10^{-4} rad (1 arcmin) Pref: 5×10^{-6} rad (1 arcsec)	1×10^{-12} m, 0.01 Å to 2×10^{-7} m, 0.2 Å	17% @ 6 keV		—	—	—	—	2.9×10^{-4} rad (60 arcsec)	5×10^{-6} rad (1 arcsec)
Equiv. Image Format Size, mm	same as a thru i	25.4×25.4	14×14	—		—	—	—	—	Optional 25.4×25.4	Optional 25.4×25.4
Picture Elements/Image	same as a thru i	10^3×10^3 = 10^6	3.6×10^3	—		—	—	—	—	~10^6	~10^6
Images/Data Set	same as a thru i	1	1	—		—	—	—	—	1	2
Images/Second	same as a thru i	0.1 to 1	3.3×10^{-4}, 0.05, 1	—		—	—	—	—	0.1	0.1 to 1
Photometric Resolution, %, bits	same as a thru i	1, 7	1%, 10^{-4}%, 7 bits (log)	10^{-4}, 7 (log)	10^{-4}, 7 (log)	10^{-4}, 7 (log)	10^{-4}, 7 (log)	32 bits	—	10^{-4} to 1%, 7 bits (log)	10^{-4} to 1%, 7 bits (log)
Equiv. Analog Data, MHz, (Hz)	1.1 to 11	1.1 to 11	(3.96×10^4)	—	—	—	—	—	—	11	1.5 to 11.4
Equiv. Digital Data, bits/image	7×10^6	7×10^6	2.52×10^4	—	—	—	—	—	—	7×10^6	7×10^6
Non-Imaging Data: Command Data, bps	6 to 256	128	128	56	210	20	8	7	7	315 (less a)	571
Science/Exp. Data, bps	3068	256	3194 (24-bit reg.)	3000	1000	1000	4000	2500	5100	21,908	25,076
Housekeeping Data, bps	256	32	128	10	180	20	20	20	20	250 (less a)	506
Special Requirements:											
Updating Cycle, Years	2	2	1	2	2	0.5	2	2	2	0.5 to 2	0.5 to 2
Mass, kg/yr (Weight, lb/yr)	3.6 (8)	13.6 (30)	27 (60)	57 (125)	82 (180)	96 (210)	23 (50)	9.1 (20)	18(40)	287 (643)	287 (643)
Volume, m^3/yr (ft^3/yr)	0.01 (4)	0.04 (1.5)	0.085 (3)	0.254 (9)	0.254 (9)	0.34 (12)	0.003 (1)	0.003 (1)	0.006 (2)	1.2 (42.5)	1.2 (42.5)
Time Reference, accuracy			10^{-7} (readout per millisec)	10^{-9}	1 MHz with 10^{-4} acc		Clock Signal: 200 kHz	1×10^{-7} 0.1 millsec res Clock Signal: 4 MHz	1 millisec	1×10^{-7} 1 millisec	1×10^{-9} 0.1 millisec
Data Storage, bits			8×10^7								> 8×10^7

* To avoid South Atlantic Anomaly.

observations. Should a single experiment fail, and not be repairable on-orbit, it will be left and the backup unit delivered for replacement during a logistics support mission. Should several major experiments, and/or any critical subsystem fail, and not be repairable on-orbit, the entire package would be returned to earth for major overhaul. Re-visits each 12-18 months appear adequate for routine maintenance and repair; however, in the event of major failure it could be revisited sooner.

Mission C - Extended Mission in Conjunction with Space Station. There does not appear to be any compelling reason for this mission over mission B from a scientific viewpoint. However, this mission may be an advantage in providing more frequent maintenance intervals at a reduced cost from individual Shuttle support launches.

5.7 POTENTIAL ROLE OF MAN

Physicist/astronauts at the space station, capable of inspecting, checking, testing, repairing, servicing, aligning, calibrating, and replacing X-ray and gamma ray sensing equipment, will accomplish initial experiment set-up in space. A team of astronomer/astrophysicist/physicists at the ground based high energy astronomy experiment control point will assist in checkout and test via monitoring and communication links. During observation/measurement operations the group of experiments will be monitored and controlled from the ground by a team of observers, physicists, and technicians utilizing computer routines pretested by simulators to aid in near real time data reduction, pointing and search control, as well as experiment control. The controllers will have override trim adjustments for optimizing experiment performance.

5.8 SCHEDULE FOR HIGH ENERGY STELLAR ASTRONOMY EQUIPMENT

Table 5-10 presents development schedules for each of the major facility items.

5.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

The launch area should have an X-ray and gamma ray astronomy laboratory with a room sufficiently large enough to accept the integrated module containing the six major experiment facility items and associated aspect sensor. A 1.82 km (1 n.mi.) long test range should be connected to the building in such a manner that the focused or collimated instruments may be pointed at radioactive sources at the end of the evacuated tube. This FPE could share the facilities for X-Ray Stellar Astronomy unless the prelaunch activities are concurrent; probably, the high energy stellar group of experiments will be launched sooner than the Section 1 experiments.

Copies of the ground based monitoring and control positions as well as information processing simulators should be available for integrated composite tests to be accomplished prior to launch.

Table 5-10. Schedule for High Energy Stellar Astronomy Equipment

EXP. NO.	FACILITY ITEM	CALENDAR YEARS -7 -6 -5 -4 -3 -2 -1	LAUNCH DATE* 0 1 2 3 4 5 6
		PHASE	
5.4.1	Wolter Type + Grazing Incidence X-ray Telescope	A B C D	
5.4.2	Venetian Blind X-ray Telescope	A B C D	
5.4.3	Asymmetric Crystal Cone Spectrometer/ Polarimeter Assemblies (9) + Combining Unit	A B C D	
5.4.4	Large X-ray Counter Array	A B C D	
5.4.5	Low Background Detector Array	A B C D	
5.4.6	High Resolution Gamma Ray Spectrometer	A B C D	
5.4.7	Large Area Spark Chamber	A B C D	
	Aspect Sensor	A B C D	
	Alignment & Calibration Equipment	A B C D	

*Launch Date should precede date for X-Ray Stellar Astronomy FPE (See Section 1.)

5.10 SAFETY ANALYSIS

Most of the high voltage employed in some of the experiment facility equipment will be enclosed within the anticoincidence shield such as for the large area spark chamber. However, the spark chamber may need to be withdrawn from its shield to replace a component in space. Appropriate precautions would be observed. One of the experiments, 5.4.6 utilizes a solid cryogen refrigerator; if sudden heating occurred in the vicinity of the solid cryogen, gases under pressure might be generated causing a pressure type explosion hazard. (Some form of pressurizable hatch cover would be employed over the array of experiment facility items with their apertures all pointed in the same direction; that large hatch would be closed when scientist/astronauts work on the equipment. It would be open when observations are made. That hatch may be a hazard.)

5.11 AVAILABLE BACKGROUND DATA

a. High-Energy Astronomy Payload Concept for Earth Orbital Operation, SMSD-SSL-195, edited by J. M. Duffie, Brown Engineering Co., August, 1968.

b. Philip C. Fisher, et al, Proposal for a HEAO X-ray Survey Experiment, 22 May 1970, Lockheed Palo Alto Laboratory, Lockheed Missiles and Space Company, Dept 52-14, Bldg 202, Palo Alto, Calif.

c. Addendum I to above, 10 Sept 1970.

d. R. Graham Bingham, et al, Flight Instrument Proposal for a Multichannel, Asymmetric - Bragg Crystal, X-Ray Spectrometer and Polarimeter for the HEAO Spacecraft, The Boeing Company, 27 May 1970.

e. Matsuaka, Masuru, Distribution of X-ray Sources and Appearance Frequency of Galactic X-ray Stars, Institute of Space and Aeronautical Science, University of Tokyo, Report No. 445, 1970.

f. H. Friedman, A Proposal to Fly X-Ray Counters and Associated Hardware, E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C.

g. K. A. Anderson, L. E. Peterson, C. S. Bowzer, and M. L. Lampton, Energy Spectra of Cosmic X-Ray Sources, 6 to 400 keV, 27 May 1970

h. A. S. Jacobson, J. R. Arnold, A. E. Metzger, L. E. Peterson, A High Resolution Gamma Ray Spectrometer for the 0.06 to 10 MeV Region, Sponsored by JPL, CIT, Pasadena, Calif. 91103, 18 May 1970.

i. G. M. Frye, A. D. Zysh, et al, High-energy Gamma Ray Astronomy with a Large Area Spark Chamber, Western Reserve University, Cleveland, Ohio, 44106.

j. NASA Document, SP-213, A Long Range Program in Space Astronomy, Position Paper of Astronomy Missions Board, July 1969.

k. DAC 58143, Orbital Astronomy Support Facility (OASF) Study, 28 June 1968

SECTION 6

INFRARED ASTRONOMY

6.1 GOALS AND OBJECTIVES

Infrared studies promise new ways of studying the nature and structure of the universe. Ground observations are restricted to certain spectral bands with one large gap from 25 to 700 μm. Since the gap is inaccessible and unknown we expect the opening of this region will substantially modify our ideas of the nature of significant processes.

Unbiased surveys of essentially all the sky are necessary to understand what kinds of infrared objects exist. Surveys at wavelengths longer than 20 μm will probably be effective in finding entirely new types of infrared objects, such as extra-galactic objects. A second essential study is a survey to determine the luminosities of a large number of sources. Since there are objects which emit a major fraction of their energy in the infrared, broadband measurements which lead to accurate total luminosities are required for all types of galactic and extragalactic objects.

Objects in survey programs would include mapping of our galaxy, other galaxies, and cosmic background radiation. Very little is known about our galaxy as a whole, and even less about its appearance in the infrared. Whole new classes of objects and types of phenomena may be being ignored for lack of survey-mapping programs. One expects to observe emission from interstellar dust clouds. The energetic processes which result in substantial infrared emission from Seyfert galaxies and a proportion of quasars give rise to emission that probably peaks near 100 μm. A variety of interesting theoretical suggestions have been made to predict weak cosmic infrared continua at various frequencies.

Observations and measurements of specific IR sources are needed to determine intensity per source and spectral characteristics to enable comparison or correlation against X-ray spectra for the same sources. The shape of the spectrum and characteristics of spectral lines enables determination of IR and X-ray emission mechanisms.

6.2 PHYSICAL DESCRIPTION

The IR telescope is unique among the astronomy instruments in that it must be cooled in its entirety to very low cryogenic (27.6°K) temperatures. This requirement results from the fact that a body will radiate energy in the IR region according to its temperature and its surface emissivity. Thus, if various parts of the optic system, such as the mirrors, the secondary supports, and the baffles, are not sufficiently cooled, they will radiate energy that may be seen as "noise" by the IR detector at the focus of the primary optical path.

The detectors in IR telescopes, at the focus of the optical path, must be kept at even lower cryogenic temperatures. To suppress "noise" in the detection and recording system, temperatures as low as 2°K are desired in some cases. Note that these extremely low temperatures apply only to the detectors and objects in the detector field of view and not to the telescope as a whole.

Table 6-1 summarizes IR stellar survey facility equipment versus proposed experiments. Table 6-2 summarizes weights, volumes, and envelope requirements of the telescope, gimbals, airlock access, supporting chilldown and cooling equipment (cryogenics), gaseous receiving tanks, and an electronics, monitoring, and display console. The following three paragraphs describe selection of operating temperature, the telescope, and its cooling equipment.

6.2.1 CHOICE OF TELESCOPE OPERATING TEMPERATURE. In principle, detector sensitivity can be increased by an arbitrary amount by sufficient cooling of the optical system. In practice, detector sensitivity is finally limited internally by preamplifier noise, generation-recombination noise and/or other sources of noise.

The operating temperature for the optics is that temperature at which the noise produced by photons is equivalent to noise produced internally in the detector. To determine this, it is helpful to consider the ideal case in which the only noise source is photons thermally emitted from the ambient medium. It can be shown that the Noise Equivalent Power (NEP) of a photon-noise-limited infrared detector is given by

$$\mathrm{NEP} = \frac{hc}{\lambda\eta} \sqrt{2\,\Delta f\,\overline{\Delta n^2}\,A\,\eta} \tag{1}$$

where λ is wavelength, η is the quantum yield, Δf is the frequency bandwidth, A is detector area, and $\overline{\Delta n^2}$ is the rms fluctuation of the photon flux. The latter is equal to the average photon flux n, for the approximation that $hc/_{\lambda} > kT$. An approximate equation for NEP suitable for broad estimates can be found from equation (1). The result is

$$\mathrm{NEP} = 10^{-19} \sqrt{n/_{\lambda}2} \tag{2}$$

where the detector is assumed to be 3.56 mm^2. The NEP is seen to be directly proportional to the square root of the photon flux, and inversely proportional to the mean wavelength λ of the photons.

Table 6-1. Facility and Experiment Equipment Versus Experiments

	Facility Items			Special Equipment		
	Telescope	Cooling Equipment	Align-ment & Calibration Equipment	Aspect Sensors Guide Star Trackers	Linear Detector Array	Michelson Inter-ferometer
6.4.1 Detector Array Scanning	●	●	●	●	●	
6.4.2 Radiometry	●	●	●	●	●	
6.4.3 High Resolu-tion Spectrometry	●	●	●	●	—	●

A plot of equation (2) is shown in Figure 6-1. Present day infrared detectors are limited to about 10^{-14} W/Hz$^{1/2}$, because of Johnson noise, preamplifier noise, and generation-recombination noise. This limit occurs at a value of the reduced photon flux n/λ^2 near 10^{10}. It is evident that cooling of telescope optics below a temperature such that the reduced photon flux from devices in the optical path is 10^{10} photons/sec is pointless, unless better detectors are developed. Detector technology may advance during the next decade, such that NEP values of 10^{-15} W/Hz$^{1/2}$ will be possible by the time the telescope is built. It is not impossible that an advance to 10^{-16} W/Hz$^{1/2}$ could be achieved in this time span. To achieve 10^{-15} W/Hz$^{1/2}$, the reduced photon flux must be decreased to 10^8 photons/sec., and to achieve 10^{-16}, it must be lowered

Table 6-2. IR Astronomy Facility Equipment

Experiment Equipment Breakdown	Mass		Occupancy Volume		Envelope	
	kg	lb	m^3	ft^3	meters	ft
IR Telescope Including Aspect Sensor ***	500	1,100	2.67	106	1.2D × 2.72	3.9D × 9
Access Space (outside)			8.05	284		
Space Occupied (exposable to vacuum)			11	(390)	2.1D × 3.1L	7D × 10L
No. 1 Cooling Assemblies (Neon Shield)						
• Liquid Neon Resupply Assembly (2 tanks, controls, and flow lines)	113	250	2.8	98	1.1 × 1.1 × 2.42	3.5 × 3.5 × 8**
• Liquid Neon	273	600	0.23	8 ft^3 in above two tanks		
• Gaseous Neon Receiving Tanks (for venting in nonobservation periods)	45.4	100	1.65	58.5	0.91 × 0.91 × 1.98	3 × 3 × 6.5
• Optional Neon Liquefaction Equipment*						
Cryostat	11	25	1.19×10^{-2}	0.353	0.13 × 0.13 × 0.7	0.42 × 0.42 × 2
Compressor	80	175	0.242	8.58	0.74 × 0.47 × 0.695	2.4 × 1.58 × 2.26
No. 2 Cooling Assemblies (2°K instruments)						
• Liquid Helium Resupply Assembly, Controls and Flow Lines	113	250	2.8	98	1.4 × 1.4 × 2.42	3.5 × 3.5 × 8
• Liquid Helium	227	500	1.53	Approx 54 ft^3 In above tanks		
• Gaseous Helium Receiving Tanks	45.4	100	1.65	58.5	0.9 × 0.9 × 2	3 × 3 × 6.5
• Helium Liquefaction*						
Cryostat	11	25	1.2×10^{-2}	0.35	0.13 × 0.13 × 0.7	0.42 × 0.42 × 2
Compressor	80	175	0.24	8.58	0.74 × 0.47 × 0.675	2.4 × 1.58 × 2.26
Basic Equipment			20	712.4		
Access Space (Inside)			54	1,902		
Sizing Requirements on Supporting Vehicle	1,500	3,300	74	2,614.4	3.7D × 3.7L	12D × 12L + Console + Cooling Equipment Space
Control Center Display/Monitoring†		120	0.04	1.4	Size Optional ~1.4 × 1.4 × 0.7	Size Optional 3.5 × 3.5 × 2

*Optional for recycling to avoid or delay necessity for cryogenics resupply. Low temperature heat sink for liquefaction to be supplied by supporting vehicle (shielded low temperature radiator).

**Part of size due to superinsulation of dewar type tanks.

***Optional gimbals and servos if telescope is not body-mounted in a free-flying vehicle would weigh 145 kg (320 lb) and occupy a volume of 1.9 m^3 (64 ft^3).

†In Space Station or control point location; local controls and amplifiers mounted in Cooling Assembly No. 1.

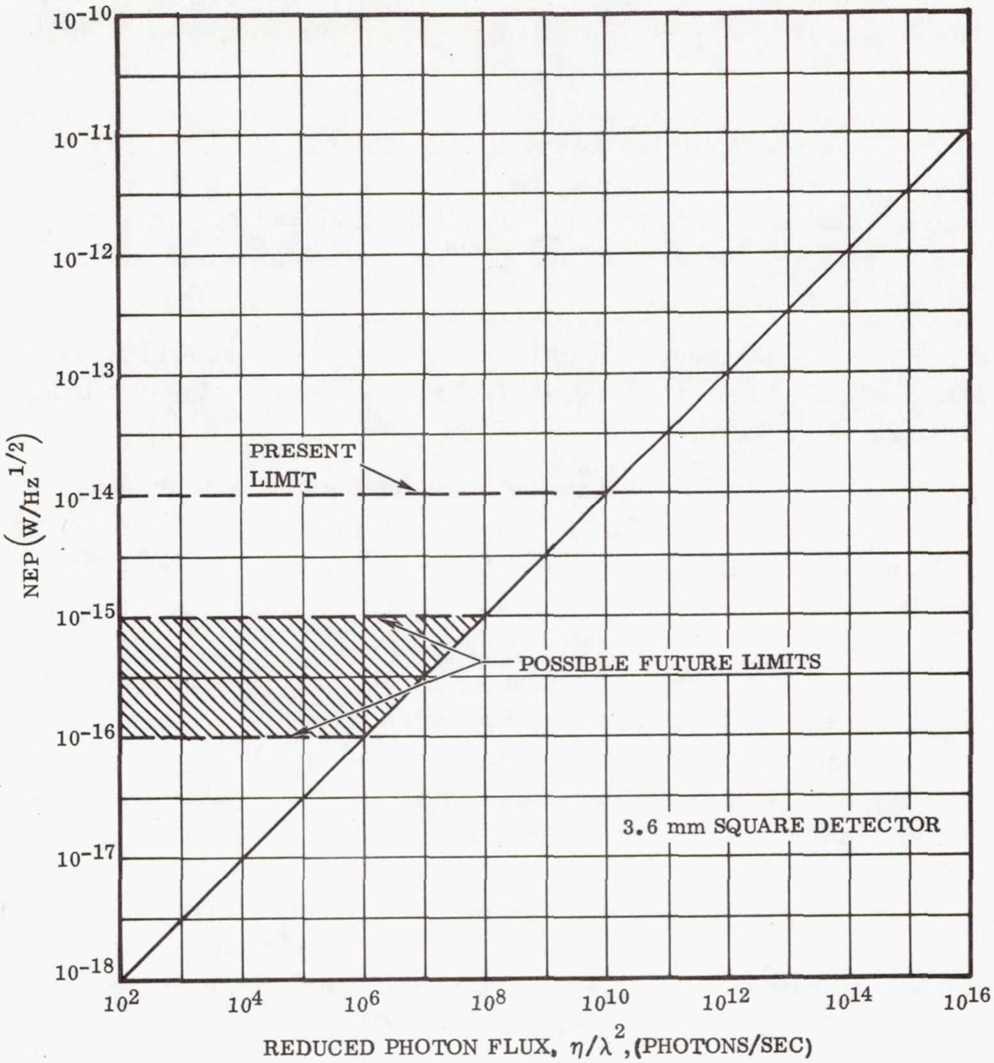


Figure 6-1. Detector Sensitivity (NEP) as a Function of Incident Thermal Photon Flux from Local Optics

to 10^6 photons/sec. The reduced photon flux from the telescope optics was estimated with the following basic assumptions:

a. The detector is at 2°K or less.

b. The detector is baffled by 2°K baffles such that it sees a solid angle equal to the f number of the telescope, f/10 in this case.

c. The effective emissivity of the optics is 0.1. Values of 0.02 are possible, but a conservative choice was made to allow for photons scattered into the detector from outside the nominal f/10 field of view. Four spectral bandwidths were calculated: 3 to 15 μm; 9 to 31 μm; 40 to 120 μm; and 300 to 500 μm. These correspond to the

spectral response obtainable from Ge (Hg), Ge (Cu), and Ge (Ga) photoconductors, and a Si or Ge bolometer with suitable filters. The reduced photon flux for each of these bandwidths is shown as a function of the optics temperature in Figure 6-2.

Examination of this figure leads to the following conclusions.

a. An optics temperature of about 15°K is required that all bandwidths shall achieve a NEP of 10^{-16} W/Hz$^{1/2}$ or less. This NEP represents a two-decade advance over the present state of the art.

b. An optics temperature of about 30°K is required so that all bandwidths shall achieve a NEP of 10^{-15} W/Hz$^{1/2}$. This NEP represents a factor of ten higher than current practice.

c. An optics temperature of 80°K permits detector performance of about 5×10^{-15} W/Hz$^{1/2}$, or about twice as good as the present state of the art for the 9 = 31 μm and 40 - 120 μm bands. The 3 - 15 μm and 300 - 500 μm bands could operate at greater sensitivity.

Figure 6-2 also shows current selected operating temperature for the one-meter diameter IR telescope as well as a backup choice and a future goal. As improved instruments are developed to enable measurements in the 500 μm to 1000 μm range, a liquid helium jacket can be added within the neon shield to the telescope design to decrease operating temperature to less than 15°K.

6.2.2 IR TELESCOPE. The IR telescope consists of a straightforward Cassegrainian optical system which is superinsulated to reject radiation from both the sun and earth. The IR instrumentation section containing an interferometer and an IR detector array is mounted directly behind the primary mirror of the Cassegrainian optics. IR detector array may be used for IR survey (scanning) and radiometry. An auxiliary optical telescope, for simultaneous visible-light imaging, is mounted to the IR telescope outside the superinsulation. Instruments coupled to the auxiliary telescope include the guide star tracker and a field viewing electronic imaging unit. The electronics are located so that the heat that they emit will not affect the temperature of the supercold IR telescope. To minimize the power being dissipated by the IR instrument, all amplification (other than preamplification) and processing of signals received is done outside the insulation. Instruments within the supercold telescope housing are rotated or translated to the focal point unless an optical IR beam-directing optical flat mirror can be cooled to about 2°K. A rotating optical flat mirror is shown in Figure 6-1.

The basic characteristics of the 1 m IR normal-incidence stellar telescope are given in Table 6-3. The basic IR telescope configuration, including optional 2-axis gimbals, is shown in Figure 6-3. An elevator/retractor mechanism, gimbals, and a pressurized service housing as used in FPE 4 may be applied in the IR astronomy FPE,

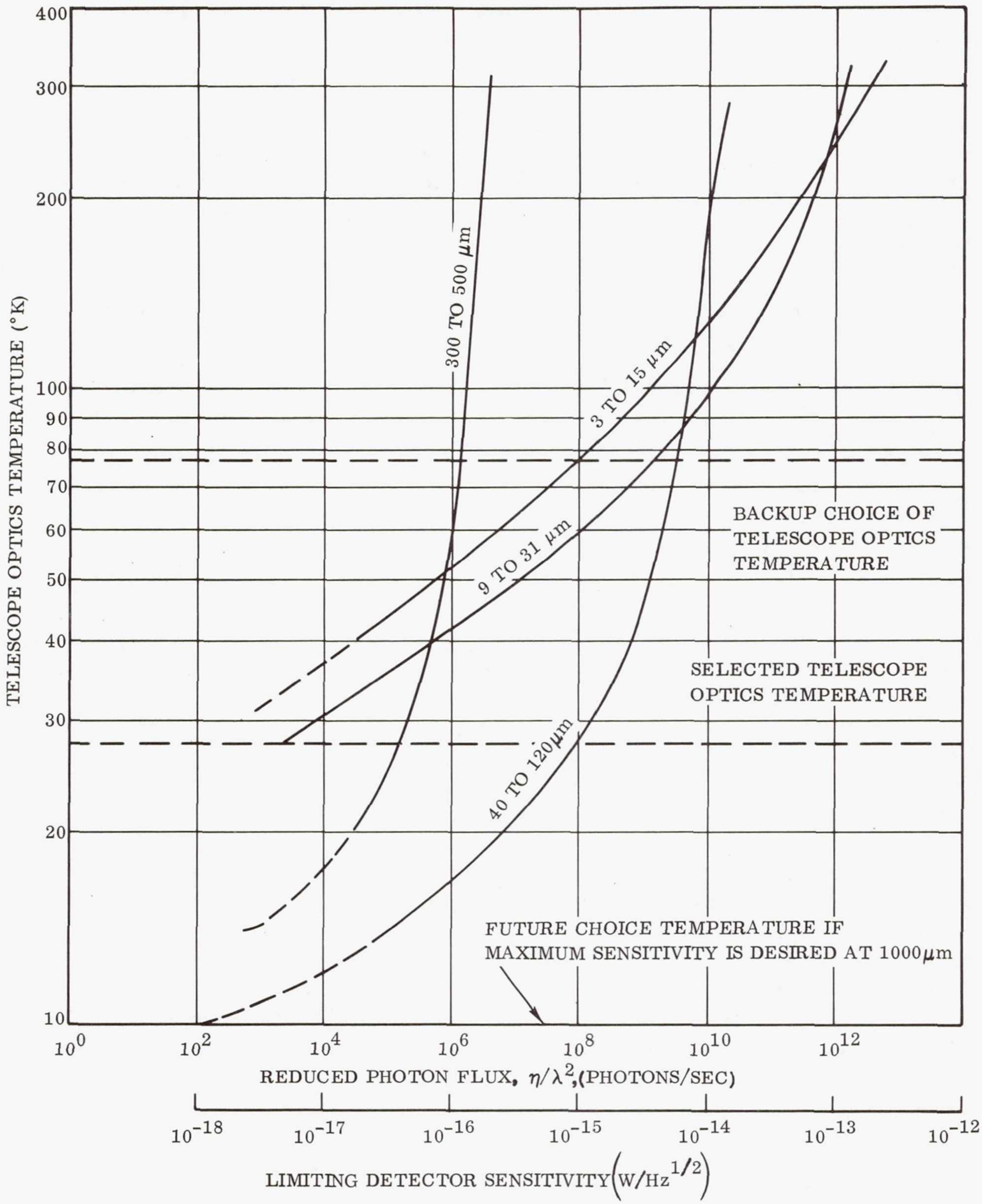


Figure 6-2. Effect of Optics Temperature on Reduced Photon Flux and Limiting Detector Sensitivity

Table 6-3. Collector Parameters for 1-Meter IR Normal-Incidence Telescope, Stellar

Aperture	1 m (3.28 ft)
Primary focal length	1.5 m (4.77 ft)
Effective focal length	10 m (32.8 ft)
Total field of view	1.45×10^{-3} rad (5 arcmin)
Angular resolution	
On axis	4.85×10^{-6} rad (1 arcsec at 4 μm)
Poorest in field of view	4.85×10^{-6} rad (1 arcsec at 4 μm)
Obscuration of aperture	6.25%
Minimum wavelength	0.7 μm
Maximum wavelength	1,000 μm
Primary f/No.	1.5
System f/No.	10
Scale at system focal plane	1×10^{-4} rad (20.6 arcsec/mm)
Resolution at system focal plane	20.6 lines/mm
Optics adjusted to give field of	42 mm at 192 element detector array.

if the telescope is used on a space station. If the telescope is used in a free-flying vehicle, no gimbals are needed.

6.2.3 IR TELESCOPE INSULATION AND COOLING EQUIPMENT. With regard to the entire telescope, two basic methods of achieving the cryogenic temperatures specified exist: passive cooling and active cooling. Passive cooling is achieved through shielding the telescope from unwanted radiation from the Earth and from the Sun to a sufficient extent that the telescope, exposed only to cold space, achieves equilibrium at the desired temperature. Active cooling involves the use of cryogenic refrigeration systems; in these systems, the cryogenic fluids may be used either on an open-cycle, resupplied basis or preferably will be continuously recycled through a closed refrigeration system (which places a power demand on the spacecraft). A 77°K option will also be considered for backup if a 27.6°K telescope cooling cannot be maintained in space with the resources available in candidate support vehicles.

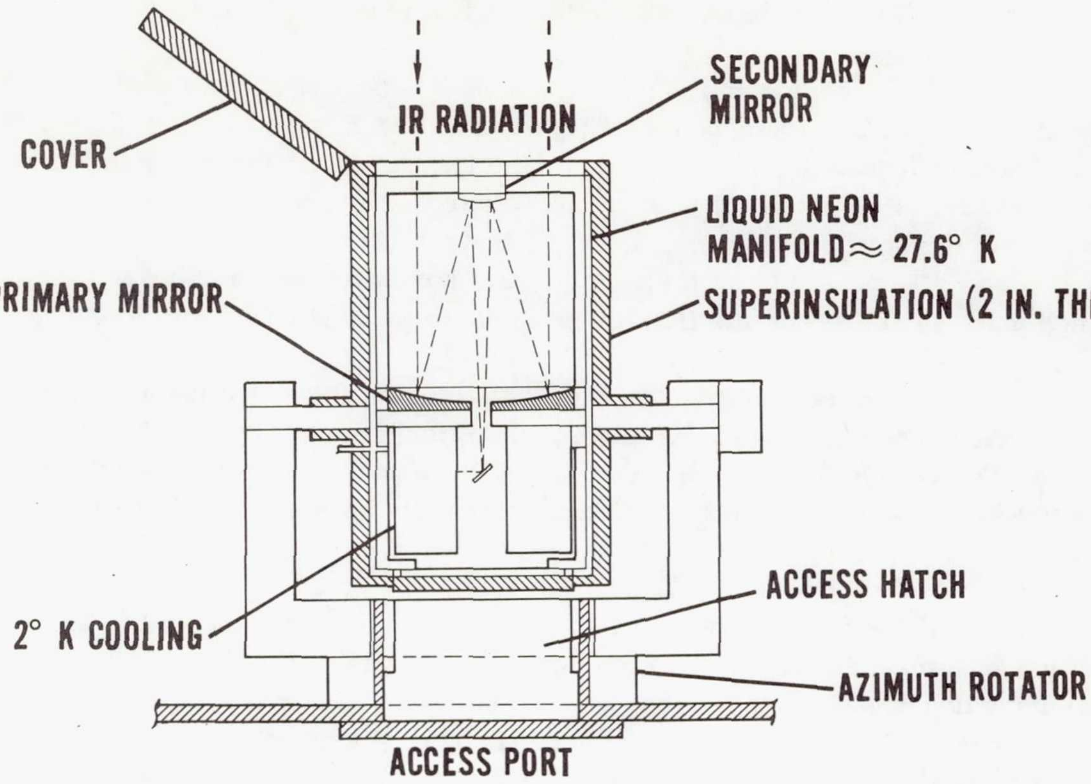


Figure 6-3. IR Telescope Configuration

6.2.3.1 Chilldown and Basic Telescope Cooling Equipment. The chilldown heat load from room temperature of 290°K to 27.6°K has been estimated as a minimum of 2.6×10^7 joules (24,000 Btu) per chilldown cycle (when liquid neon shield and supply tank initial heat loads are considered) for an IR telescope 1 m (3.28 ft) diameter, and 2.7 m (8.85 ft) long and of 500 Kg (1,100 lb) of mass. It is assumed that the telescope structure incorporates a liquid neon shield substantially surrounding the cylindrical telescope walls. Two inches of superinsulation are utilized outside the liquid neon shield as well as at the rear access hatch and the pivotable aperture cover. With the telescope chilled to 27.6°K and with the hatch and aperture cover closed, the net heat gained through the superinsulation and the low-conductivity altitude-axis pivot points is estimated to be 264 joules/hr (0.25 Btu/hr). It is expected chilldown will be accomplished before ground-launch or at the Space Station if maintenance is required.

When the telescope aperture is open and pointed to deep space, i.e., >90° away from the center of the Sun and from the center of the Earth, the net heat loss with respect to 27.6°K telescope optics has been estimated to be near zero. Hence a temperature hold capability is apparent if the instruments inside the telescope do not generate extra heat. Some heat will be gained since the telescope will not always point to deep

space in its operations. That heat gain has been estimated to be about 3,600 joules/hr or 1 watt hour (3.4 Btu) average per hour (about 0.092 lb of neon per hour).

Chilldown is expected to be accomplished once each 180 days after a servicing, maintenance, alignment, and instrument retrofit period of four hours. During the servicing period the rear access hatch is opened and the instrument chamber behind the mirror is pressurized (a pressure gate is placed across the Cassegrain light beam aperture in the mirror support base). Only the instrument section is warmed up during servicing. Neon used from the supply tanks for chilldown potential will be replenished prior to release of the IR astronomy facility for observation.

The chilldown and sustained cooling equipment expected on the experimental carrier vehicle are listed under cooling in Table 6-2. Two liquid neon supply tanks capable of holding about 136 kg (300 lb) of liquid neon each will be packaged together with valves, venting devices, regulators, and temperature control equipment in a liquid neon supply assembly.

Two insulated receiving tanks combined in another assembly are expected to be used to collect gaseous neon during observation periods. The gaseous neon will be vented to space during non-observation periods or will be reliquified by the optional liquefaction equipment listed in Table 6-2. If the gaseous neon is kept at fairly low temperature (less than 40°K), power load for reliquefaction is expected to be between 100 and 1000 watts.

Total power load for a desired optional closed cycle cooling system employing liquid neon for telescope optics cooling and super fluid helium at 2°K for detector and other instrument cooling (see Section 6.2.3.2) is expected to be between 200 and 2000 watts. (Further detailing of design and cooling is needed to arrive at firm numbers.)

6.2.3.2 Detector and Spectrometer Cooling. The 192 element scanning detector array is uniformly cooled to 2°K by a combination of Peltier cooling and heat exchange with a liquid helium cryostat. The liquid helium cryostat located in the telescope is separated from a surrounding jacket of liquid neon by special nonpermeable super-insulation. Pumping is used on the liquid helium in the vicinity of the detector to lower the detector element temperature to 2°K. A maximum heat load of 0.2 watt results in a super fluid helium use rate of about 1.9 lb per day or about 36 kg (80 lb) per six months. An equivalent heat load and helium usage per six months is expected for Michelson Interferometer cooling. However, only one instrument is active at a given time. Total liquid helium usage for one operating instrument per six months, excluding supply equipment losses is expected to be about 155 kg (342 lb). Allowance for alternative pumping methods to cool to 2°K and for supply equipment losses brings the six-month operations cycle usage to about 230 kg (500 lb) of liquid helium. If both instruments are active for quick switchover, helium consumption is doubled.

A set of liquid helium supply tanks (Dewars) and control equipment equivalent in size to that required for the neon cooling loop is listed in Table 6-2 together with gaseous helium receiving tanks and optional liquefaction equipment. The liquefaction power load is estimated to be between 100 and 1000 watts depending upon helium conservation policies and cooling loop design utilized. Possibly the helium liquefaction equipment would operate with respect to the neon liquid heat sink.

6.3 EXPERIMENT REQUIREMENTS SUMMARY

Table 6-4 summarizes requirements of the IR astronomy experiments utilizing the facility equipment listed in Tables 6-1 and 6-2.

6.4 EXPERIMENT PROGRAM

The experiments initially utilized for IR stellar survey will include alignment, calibration, guide star acquisition, and desired object location processes in each of the experiments as well as the primary experiments. The three initial primary experiments are linear detector array scanning for new sources, radiometry, and high resolution spectrometry of previously located sources.

6.4.1 DETECTOR ARRAY SCANNING

6.4.1.1 Scientific or Technical Goals. The purpose of this experiment is to conduct an all-sky survey in the 5 μm to 500 μm range, and in particular, to search for infrared radiation sources associated with high-energy phenomena observed in the X-ray and gamma ray portions of the spectrum. Even with the present state of infrared technology, a great many infrared emitters, such as Seyfert galaxies, brighter quasi-stellar objects, infrared nebulae, etc. have been detected. An all-sky map of these kinds of sources (as well as X-ray sources, which emit IR) will add greatly to our understanding of the abundance and distribution of IR sources.

The scanning type survey is expected to map the celestial sphere for infrared sources with resolution and positional accuracy of better than 1 arc minutes and with a sensitivity of at least 10^{-17} watts/cm^2 in the 5 to 500 μm range and the 150 to 800 μm region.

The search for IR sources will enable location of IR emitters for specific observation by experiments 6.4.2 and 6.4.3.

6.4.1.2 Description. To accomplish an IR sky survey within a reasonable operating period, a detector array can be incorporated into the telescope assembly at or near the focal point. Scanning of the heavens can then be accomplished by holding the IR telescope at a given angle with respect to the orbit plane and scanning a full circle (generally less than a great circle) on the celestial sphere as the orbit is traversed. The angle measured from the orbit plane is changed for each successive orbit traverse

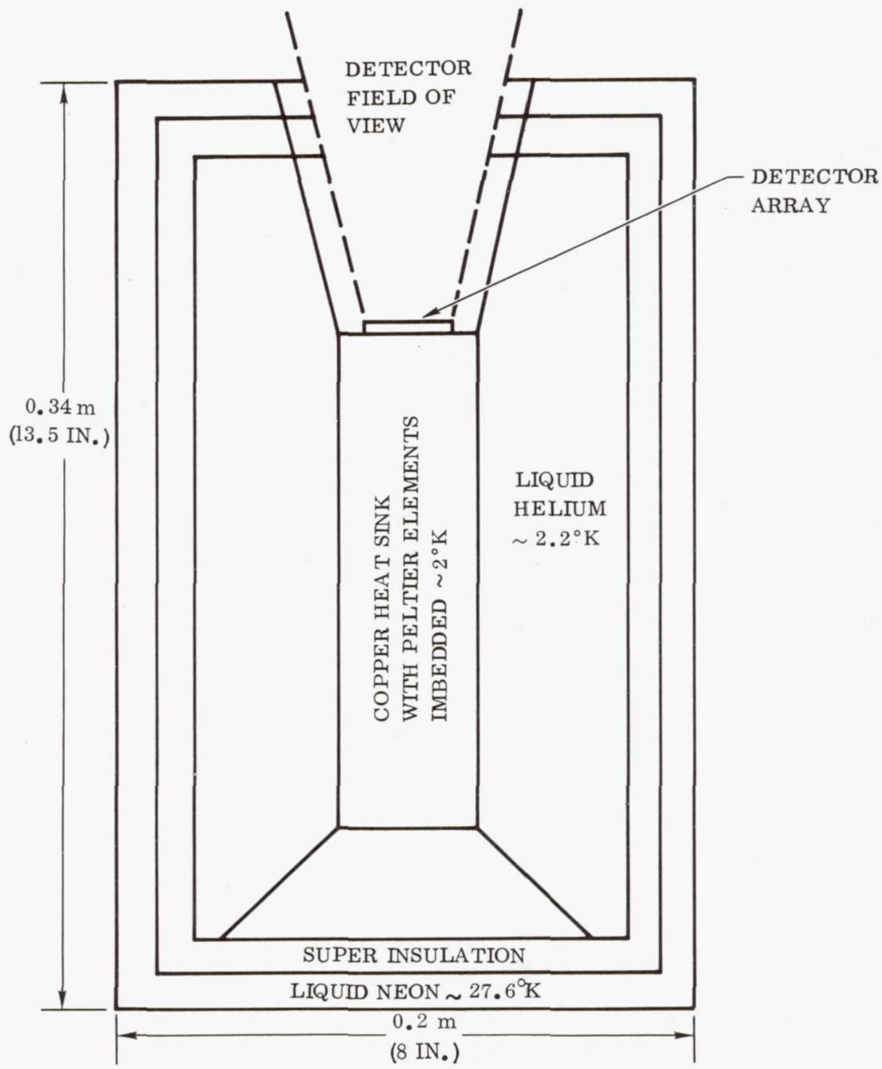
Table 6-4. IR Astronomy Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
6.4.1 IR Detector Array Scanning	Minimum 1500 kg (3300 lb)	11 (390) outside +74 (2614.5) inside, of which 54 (1902) is for access to IR telescope support equipment	Outside: 2.1D × 3.1L (7D × 10L) Inside: working space 3.66D × 3.66L (12D × 12L) +2 cryogenics supply assemblies, ea. 1.1 × 1.1 × 2.4 (3.5 × 3.5 × 8) +2 gas receiving assemblies, ea. 0.92 × 0.92 × 2 (3 × 3 × 6.5)	Average: 250 Peak: 300 Standby: 200 Total Per Orbit: 50 minutes at 300W 42 minutes at 200W	Astronomer Astrophysicist Astronaut	Temp Limits:* 27.6° K ± 1° K Ops Atmosphere: 1.333×10^{-4} N/m^2 Gravity Level: $<10^{-3}$g for stability Radiation Sensitivity: <1 mrad/hr $\Delta T < 1°$ K	Setup: 24 Ops Cycle: 1.533/orbit for 1 yr Maintenance: 16 per 180 days	Picture Elements Per Image: — Images/Sec: — Digital Picture Data: — Non Imaging Data: Command 32 bps Science/Exps: 9376 bps Housekeeping: 32 bps	Pointing Accuracy: 2.9×10^{-4} rad (1 arcmin) or better Pointing Stability: 2.9×10^{-5} rad (6 arcsec) Max Slew Rate: 11.6×10^{-4} rad/sec (240 arcsec/sec) Min Slew Rate: — Pointing Hold Time: — Scanning: 3000 sec per orbit	Desired Incl: 50° to 60° Acceptable Incl: 25° to 55° Desired Alt: 500 to 560 km (270 to 300 n.mi.) Acceptable Alt: 460 to 740 km (250 to 400 n.mi.)	27.3 kg (600 lb) liquid neon per 180 days. 227 kg (500 lb) liquid helium per 180 days (including contingencies). Desired Option: closed loop (reliquefaction) with 200 to 2000 W power input.
6.4.2 IR Radiometry (uses above linear array)	Same as above	Same as above		Average: 250 Peak: 300 Standby: 200 Total: 1650 watt-hours	Astronomer Astrophysicist Astronaut	Temp Limits:* 27.6° K ±1° K Ops Atmosphere: 1.333×10^{-4} N/m^2 Gravity Level: $<10^{-3}$g during hold Radiation Sensitivity: 1 mrad/hr $\Delta T < 0.5°$ K	Setup: 22 Ops Cycle: 2.33 to 5.5 Maintenance: 15 per 180 days	Picture Elements Per Image: Aspect sensing 10^6 Images/Sec: 1 Digital Picture Data: 7×10^6 bps Non Imaging Data: Command 32 bps Science/Exps: 200 bps Housekeeping: 32 bps	Pointing Accuracy: 4.85×10^{-6} rad preferred (1 arcsec) Pointing Stability: 5×10^{-6} radian (< 1 arcsec) Max Slew Rate: 17.4×10^{-4} rad/sec (360 arcsec/sec) Min Slew Rate: 5×10^{-6} rad/sec (~1 arcsec/sec) Pointing Hold Time: 900 to 14,400 sec	Desired Incl: 50° to 60° Acceptable Incl: 25° to 55° Desired Alt: 500 to 560 km (270 to 300 n.mi.) Acceptable Alt: 460 to 740 km (250 to 400 n.mi.)	Pointed at selected IR sources. For absolute brightness measurement per selected spectral band.
6.4.3 High Resolution IR Spectrometry	Same as above	Same as above		Average: 250 Peak: 300 Standby: 200 Total: 1650 watt-hours	Astronomer Astrophysicist Astronaut	Temp Limits:* 27.6° K ±1° K Ops Atmosphere: 1.333×10^{-4} N/m^2 Gravity Level: $<10^{-3}$ g during hold Radiation Sensitivity: 1 mrad/hr $\Delta T < 0.5°$ K	Setup: 24 Ops Cycle: 2.33 to 5.5 Maintenance: 16 per 180 days	Picture Elements Per Image: Aspect sensing 10^6 Images/Sec: 1 Digital Picture Data: 7×10^6 bps Non Imaging Data: Command 32 bps Science/Exps: 1200 bps Housekeeping: 32 bps	Pointing Accuracy: 4.85×10^{-6} rad (1 arc sec) Pointing Stability: $<5 \times 10^{-6}$ rad Max Slew Rate: 17.4×10^{-4} rad/sec (360 arcsec/sec) Min Slew Rate: $< 5 \times 10^{-6}$ rad/sec (~1 arcsec/sec) Pointing Hold Time 3000 to 14,400 sec	Desired Incl: 50° to 60° Acceptable Incl: 25° to 55° Desired Alt: 500 to 560 km (270 to 300 n.mi.) Acceptable Alt: 460 to 740 km (250 to 400 n.mi.)	Pointed at selected IR sources. Spectral shape and lines analysis.

*2° K for super-fluid-helium-cooled detectors.

until the entire celestial sphere is scanned. Considering the 5 arc-min field of the optics of the telescope, a 42-mm long element array of detectors, weighing about 4 kg, would enable an 11.6×10^{-4} rad (4 arcmin) "slice" of the celestial sphere, 1.18×10^{-5} rad (or 2.5 arcsec) element at 5 μm to 800 μm wavelength, to be obtained per orbit transverse. See Figure 6-4 for Detector Package Outline. At the expected operational altitude of 500 km (270 n.mi.) only an 11.6×10^{-4} rad (4 arcmin) field of view is required to search one-half of the celestial sphere in a half year of continuous scanning, particularly if the telescope is not allowed to view closer than 1.58 rad (90°) with respect to the center of the Sun.

The scanning function will be accomplished by using a linear array of infrared detectors such as used by Cal Tech in 1965. The secondary mirror of the California Institute of Technology telescope was vibrated at 20 Hz, such that an image of a point source fell alternately on one or the other of two adjacent cells. Only the alternating signal was amplified. This method provides a more economical use of light than does a mechanical chopper. It is proposed to follow a similar procedure for the sky survey



with the cold IR telescope. A special difficulty arises due to the different sizes of detector required in different parts of the spectrum. The detector should not be smaller than the size of the diffraction image, which becomes large in the far infrared. For an f/10 telescope, the approximate sizes of the images of a point source versus wavelength are as follows:

Average Wavelength	Image Size
15 μm	0.37 mm
30 μm	0.76 mm
120 μm	3.0 mm
500 μm	12.5 mm

A convenient detector size is 1-mm square, and this will suffice to about 50 μm. Beyond 50 μm, detectors must be considerably increased in size. A compromise value might be 5 mm. This is too large for 120 μm, and too small for 500 μm, but would simplify detector array construction and telescope operation. Four linear array pairs are suggested: two pairs of 5-mm square detector linear arrays and two pairs of 1-mm square detector linear arrays. Eight detectors are used in each of the 5-mm linear arrays, and 40 in each of the 1-mm linear arrays. A total of 192 detectors are used. The total array dimensions will be about 3×4.5 cm. Ideally, the image displacement produced by the vibrating secondary mirror should equal twice the detector dimension, or 2 mm for the small detectors and 10 mm for the large ones. Either a compromise amplitude might be used, or the survey performed twice. The power dissipated in the array is estimated at about 200 mW.

6.4.1.3 Observation/Measurement Program. To survey the celestial sphere, at least two series of orbital scans centered about six months apart are necessary to enable coverage of the celestial sphere at least 1.58 radians (90°) away from the center of the Earth and the center of the Sun. Each scan will occur during the 3.15 rad (180°) of the orbit that the IR telescope can be aimed at least 1.58 rad (90°) away from the center of the Sun and the center of the Earth. The IR telescope is locked during each scan to a selected scan-angle center in the plane that passes through nadir and is perpendicular to the orbital plane. The telescope aperture is usually closed when the telescope is pointing closer than 1.58 rad (90°) to the center of the sun to avoid excessive heat input and liquid neon and helium losses.

At least 2700 scans of 11.6×10^{-4} rad (4 arcmin) angular width, for the 3.15 rad (180 deg) of orbit that is greater than 1.58 rad (90°) from the center of the sun, are needed at two circumsolar regions about six months apart to map the celestial sphere. Therefore, 5400 orbits are needed to complete the celestial sphere. Actually, the telescope pointing may approach several degrees nearer to the Sun than 1.58 rad (90°) if an appropriate shade (the aperture cover) is used. Hence, for a 92-minute orbit at

about 500 km (270 n.mi.), about 50 minutes will be used for scanning; during the remaining part of the orbit, periodic checks, calibration, and IR telescope scan angle adjustment will be made.

A typical observation/measurement sequence including set up and maintenance follows:

Ops	Task	Duration Per Cycle, Hours	Number of Cycles
S/U	Telescope/Instrument Setup (including chilldown)	20* + 4	1
a.	Alignment & Calibration	1.0	1 per 48 hr
b.	Periodic Checkout	0.2	1 per orbit
c.	Periodic Calibration	0.1	1 per orbit
d.	Telescope Scan Angle Adjustment	0.1	1 per orbit
e.	Protective Aperture Cover Opening	0.1	1 per orbit
f.	Stabilization Prior to Scan	0.1	1 per orbit
g.	Survey Scan Observation	0.833	1 per orbit
h.	Close Protective Aperture Cover	0.1	1 per orbit
i.	Repeat (b) through (h)	1.533	5400 orbits

Since 2700 orbits requires about 180 days, it will take a little more than one year to completely survey the celestial sphere. Probably the survey will be done in segments in between higher priority detailed observations on specific selected IR sources. Also periodic maintenance will require some time. Estimates of maintenance required is as follows:

Ops	Task	Duration Per Cycle, Hours	Number of Cycles
M	Maintenance		
S/M	Scheduled Maintenance	14*	1 per 180 days
U/M	Unscheduled Maintenance	14* + 2	1 per year

6.4.1.4 Detector Array Experiment Interface, Support, and Performance Requirements. Interface, support, and performance requirements are presented in Table 6-6 in Section 6.5.

*Includes 10 hours for gradual warmup and chilldown. Also time for liquid neon and helium resupply.

6.4.1.5 Role of Man. For the IR telescope and the detector array scanning experiment, man prepares the IR telescope equipment and experiments which are probably delivered as a modular integrated assembly to be docked to the supporting Space Station or are already installed in a free-flying vehicle, if so utilized. The cryogenic cooling system will require manned attention during in-space setup, checkout, chilldown, and replenishment operations. Man's ability to unlock, inspect, align, and prepare for deployment, minimizes need for complex mechanisms such as automatic caging systems. Man can periodically inspect and test the equipment and when a failure is found he can replace the failed unit. In addition, for periodic updating, man can remove the previous units and replace them with the new ones.

6.4.1.6 Available Background Material

a. H. C. Johnson and A. B. Meinel, An All-Sky Survey for Infrared Radiation (50 to 800 microns) Associated with High Energy Phenomena, U. of Arizona, MIT, ASE, 27 May 1970.

b. Conferences with R. Cameron, Ames Research Center, Summer & Fall, 1970.

6.4.2 RADIOMETRY

6.4.2.1 Scientific or Technical Objectives. The radiometry experiment will utilize the detector array to enable long-term observation/measurements of selected IR sources. For each selected source, precision photometric brightness and variation measurements will be made versus a selected spectral bandwidth.

The objective of the radiometry experiment is to make longer term observations of sources as weak as 10^{-20} W/cm^2 at selected spectral bandwidths from 5 μm to about 100 μm.

6.4.2.2 Description. The radiometry equipment will be the same as that used for detector array scanning as described in Section 6.4.1.2 but method of observation will differ. In the radiometry experiment the IR telescope is pointed at the object of interest for long periods of time rather than being systematically scanned.

The minimum detectable flux F_m is arbitrarily defined as three times the noise equivalent power (NEP) of the detectors. For a dual detector system, in which the beam is switched from one detector to another:

$$F_m = \frac{3\,(NEP)}{(2)^{1/2}\,(2\pi t)^{1/2}\,A}$$

where t is the observation time, and A is the effective collecting area of the telescope. It assumed that the NEP is 5×10^{-15} W/Hz$^{1/2}$ at all bandwidths, the observation or dwell time is 1 sec in the survey mode, and at least 15 minutes in the radiometric

mode, and the effective telescope area is at least 5000 cm^{2*}. The telescope sensitivity is then 5×10^{-8} $watt/cm^{2*}$ in the survey mode and 3×10^{-20} $watt/cm^{2*}$ in the radiometric mode. The best ground-based measurements give a sensitivity of 2×10^{-18} $watts/cm^2$ for an integration time of one hour.

6.4.2.3 Observation/Measurement Program. The operations activities for setup, maintenance, and resupply will parallel those for the 6.4.1 experiment; that is, the telescope does not have to be prepared again if set up for detector array scanning. However, the typical operational durations are set forth in the following tabulation to enable a complete picture of the total operations cycle.

Ops	Task	Duration Per Cycle, Hours	Number of Cycles
S/U	Telescope/Instrument Setup (including chilldown)	20** + 2	1
a.	Alignment & Calibration	1.0	1 per cycle
b.	Periodic Checkout	0.2	1 per cycle
c.	Periodic Calibration	0.1	1 per cycle
d.	Guide Star Acquisition	0.1	1 per source
e.	Object Location	0.1	1 per source
f.	Object or Source Observation Measurement	0.25 to 4	1 per source
g.	Total per Source	1.85 to 5.5	per source
h.	For next source repeat (a) thru (f)	1.85 to 5.5	per source
M	Maintenance		
S/M	Scheduled Maintenance	14** + 1	1 per 180 days
U/M	Unscheduled Maintenance	14** + 2	1 per year

6.4.2.4 Radiometry Experiment Interface, Support, and Performance Requirements. Table 6-6 in Section 6.5 includes interface, support, and performance requirements for the radiometry experiment. Also, shown in the table, is the data requirement for the aspect sensor which can produce 1 image per second at 10^6 picture elements/image.

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* At 4 μm, effective area should be about 7.38×10^5 cm^2.

** Includes 10 hours for gradual warmup and chilldown. Also time for liquid cryogenics resupply.

That data rate is generated during the time the particular (previously cataloged) star is being located by interpolation and identification of stars in the vicinity. It is assumed that the IR telescope guide star trackers are optically coupled to the aspect sensor and will operate automatically after the initial pointing adjustment of the telescope axis with respect to the guide stars.

6.4.2.5 Potential Role of Man. Man enables initial setup, installation, alignment, and calibration in space as well as remote control and monitoring of the radiometer operations from a console in the supporting vehicle. The liquid neon cooling facilities, in particular, will benefit from the presence of man. Man will periodically (at six-month intervals) maintain, service, align, and calibrate the radiometer equipment better than can be accomplished periodically by remote control. Particularly, adjustment ranges will be centered to enable trimming on both sides of the optimum performance points.

6.4.2.6 Available Background Data

a. H. L. Johnson and A. B. Meinel, All-Sky Survey for Infrared Radiation (50 - 800) microns Associated with High Energy Phenomena, U. of Arizona, MIT, ASE, 27 May 1970.

b. DAC Reports 58142 and 58143, Volumes II and III of Orbital Astronomy Support Facility Study, 28 June 1968, by Douglas Missiles and Space Systems Division, Santa Monica, California.

6.4.3 HIGH RESOLUTION SPECTROMETRY

6.4.3.1 Scientific or Technical Objectives. High-resolution spectrometry over the total IR spectrum of 1 μm to 1000 μm is desired for each IR source investigated. (However, present state of the art indicates that several spectrometers may need to be utilized one at a time to cover the spectrum. One interferometer might cover 5 to 15 μm with 0.01 μm precision; a second interferometer 15 to 500 μm with 0.01 μm precision, etc.) Ultimately, the continuous spectrum from 1 μm to 1000 μm needs to be measured per source to obtain characteristics that would define IR emission mechanisms. Simultaneous observations should be obtained in the IR spectrum and the X-ray spectrum by cooperating X-ray astronomy and IR astronomy telescopes pointed at the same source at the same time to obtain correlated data for additional conclusions about emission mechanisms. As the state of the art improves, a spectral resolution of 2500 or better is desired in the IR spectrum to enable identity of spectral lines.

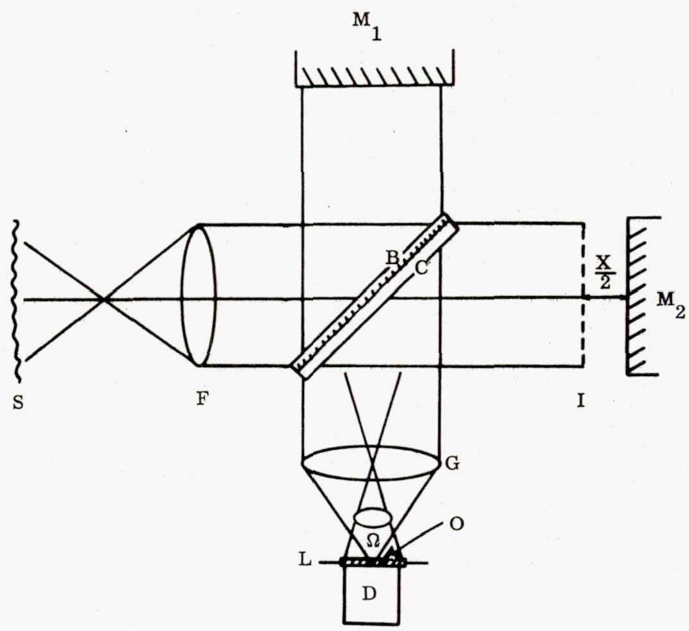
The technical objective is then successive improvement in IR spectral coverage and resolution in space for low level inputs.

6.4.3.2 Interferometer Description. An interferometer shown schematically in Figure 6-5 is incorporated in the instrumentation section of the IR telescope for high-resolution spectrometry. The infrared energy collected by the telescope is passed through a hole in the unit where the interferometer is to be used. The optical arrangement of the interferometer divides the energy to create an interference pattern. A detector reads out the interference pattern as a function of time and the position of the movable mirror. See Figure 6-6 for instrument outlines.

Although a Michelson-type of interferometer is depicted in Figure 6-5, other types of interferometers could also be considered as instruments to be periodically substituted into the IR telescope. Specific design parameters of interferometer options are shown in Table 6-5.

Table 6-5. Interferometer Parameters

Parameter	Michelson	Interferometer	Options
Option:	A	B	C
Wave Length			
Minimum, μm	5	15	0.7
Maximum, μm	15	50	100
Resolution, $\frac{\lambda}{\Delta \lambda}$	500	1500	2500
Beam Angular Stability Stability Desired in Arc Secs	6	3	1
Detector Type	Ge(Hg)	Si	(Not chosen)
Detector Temperature	2°K	2°K	2°K
Instrument Size, m (ft)	0.15D × 0.4L (0.5D × 1.3L)	0.15D × 0.4L (0.5D × 1.3L)	0.3D × 0.46L (1D × 1.5L)
Instrument Mass, kg (lb)	59 (125)	59 (125)	10 (22) +
Control Unit Mass, kg (lb)	22.5 (50)	22.5 (50)	22.5 (50)



b BEAM-SPLITTER

C COMPENSATING-PLATE

D DETECTOR

F FORE-OPTICS COLLIMATING LENS

G CONDENSING LENS

I IMAGE OF FIXED MIRROR (M_1)

L LIMITING APERTURE PLATE

M_1 FIXED MIRROR

M_2 MOVING MIRROR

O OPTICAL FILTER

S SOURCE

X OPTICAL PATH DIFFERENCE

Ω ACCEPTABLE SOLID ANGLE OF RADIATION

Figure 6-5. Michelson Interferometer

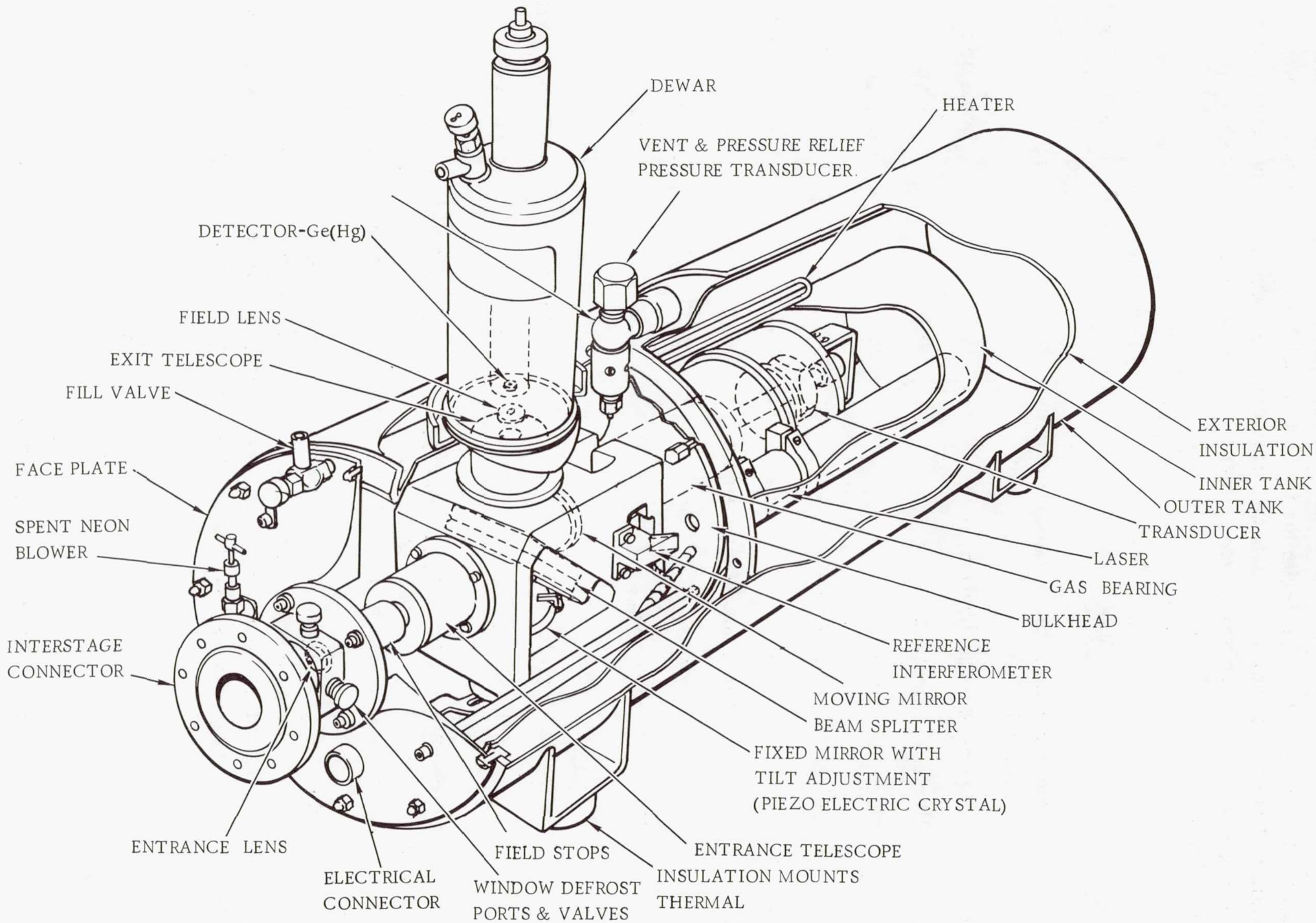


Figure 6-6. Cooled Interferometer

6.4.3.3 Observation Measurement Program. The operations, maintenance, and resupply activities will parallel those for the 6.4.1 and 6.4.2 experiments, being accomplished during the same maintenance and servicing periods to conserve chilldown and cooling resources. The setup, experiment operations, and maintenance cycles are as follows:

Ops	Task	Duration per Cycle, Hours	Number of Cycles
S/U	Telescope/Instrument setup (including chilldown)	20* + 4	1
a.	Alignment & Calibration	1.0	1 per source
b.	Periodic Checkout	0.2	1 per source
c.	Periodic Calibration	0.1	1 per cycle
d.	Guide Star Acquisition	0.1	1 per cycle
e.	Object Location	0.1	1 per source
f.	Source Observation/Measurement	0.1	1 per source
g.	Total Per Source	2.33 to 5.5	per source
h.	For next source repeat (a) thru (f)	2.33 to 5.5	per source
M	Maintenance		
S/M	Scheduled Maintenance	14* + 2	1 per 180 days
U/M	Unscheduled Maintenance	14* + 2	1 per year

6.4.3.4 High-Resolution Spectrometry Experiment Interface, and Performance Requirements. Table 6-6 in Section 6.5 contains the interface, support, and performance requirements for the high resolution spectrometry experiment.

6.4.3.5 Potential Role of Man. Man will be able to remove the interferometer unit at six-month intervals and place it into a checkout and calibration test set which automatically cycles the interferometer through the spectrum, indicating adjustments and repairs required. Occasionally the unit is replaced with an updated unit and the old one is sent back to earth.

* Includes 10 hours for gradual warmup and chilldown. Also time for liquid cryogenics supply.

Table 6-6. FPE Interface, Support, and Performance Requirements

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	6.4.1 Detector Array Scanning	6.4.2 Radiometry	6.4.3 High Resolution Spectroscopy	ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Experiment Facility Equipment Used:	IR Telescope Cooling Equip.	IR Telescope Cooling Equip. Aspect Sensor	IR Telescope Cooling Equip. Aspect Sensor		
Launch Mass, kg (Weight, lb)	1500 (3300)	1500 (3300)	1500 (3300)	1500 (3300)	1500 (3300)
Logistics Support					
Consumables, kg/180D (lb/180D)	272 kg (600 lb) LNe 226 kg (500 lb) LHe	272 kg (600 lb) LNe 226 kg (500 lb) LHe	272 kg (600 lb) LNe 226 kg (500 lb) LHe	272 kg (600 lb) LNe 226 kg (500 lb) LHe	272 (600) LNe + 226 (500) LHe initially + closed operation there-after
Spares, kg/180D (lb/180D)					
Crew Support					
Initial Setup, Manhours/180D	24*	22*	24*	30	30
Periodic Serv. & Maint., Manhours/180D	16*	15*	16*	19	19
Operation, Remote Control, Manhours/Observation Cycle	1.53 per orbit	2.33 to 5.5	2.33 to 5.5	1.53 to 5.5	2.33 to 5.5
Electric Power:					
Peak Load, Watts	300	300	300	300	300
Average Load, Watts	250	250	250	250	250
Standby Load, Watts	200	200	200	200	200
Environmental Control					
Desired Vehicle Heat Sink Temp, °K					
Temp. Limits, Stowed, °K	Prechilled to 27.6*	Prechilled to 27.6	Prechilled to 27.6	Prechilled to 27.6	Prechilled to 27.6
Temp. Range, Ops., °K	27.6, 2**	27.6, 2**	27.6, 2**	27.6, 2*	27.6, 2**
Max. Temp. Difference, °K	1	0.5	0.5	0.5 to 1	0.5 to 1
Relative Humidity, %	~ 0	~ 0	~ 0	~ 0	~ 0
Atmosphere Limit, N/m^2 (psi, torr)	0 to 10^5, 1.33×10^{-4}† (0-15, 10^{-6} prefer.)	0 to 10^5, 1.33×10^{-4}† (0-15, 10^{-6} prefer.)	0 to 10^5, 1.33×10^{-4}† (0-15, 10^{-6} prefer.)	0 to 10^5, 1.33×10^{-4} (0-15, 10^{-6} prefer.)	0 to 10^5, 1.33×10^{-5} (0-15, 10^{-7} prefer.)
Cleanliness Class	10,000	10,000	10,000	10,000	10,000
Gravity Level, Max. g	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$
Radiation Sensitivity, millirad/hr	< 1	< 1	< 1	< 1	< 1
Contamination Sensitivity	Moderate to severe***	Moderate to severe***	Moderate to severe***	Moderate to severe***	Moderate to severe***

* Includes 14 hr for warmup & childown
** Detector temperature

*** Severe if hot environmental leaks and H_2O dumps are present.
† 1.33×10^{-4} N/m^2 (10^{-7} torr) preferred.

Table 6-6. FPE Interface, Support, and Performance Requirements, Contd

INTERFACE OR SUPPORT PARAMETERS / EXPERIMENT	Detector Array	Radiometry	High Resolution Spectroscopy						ACCEPTABLE SUPPORT	DESIRABLE SUPPORT
Orbital Parameters:										
Desired Inclination, deg	50 to 60	50 to 60	50 to 60						50 to 60	50 to 60
Acceptable Inclination, deg	25 to 70	25 to 70	25 to 70						25 to 70	25 to 70
Desired Altitude, km (n.mi.)	500 to 560 (270 to 300)	500 to 560 (270 to 300)	500 to 560 (270 to 300)							500 to 560 (270 to 300)
Acceptable Altitude, km (n.mi.)	460 to 740 (250 to 400)	460 to 740 (250 to 400)	460 to 740 (250 to 400)						460 to 740 (250 to 400)	
Orientation:										
Observed Object Location	>90° from sun or earth center	>90° from sun or earth center	>90° from sun or earth center						>90° from sun or earth center	>90° from sun or earth center
Observed Object Brightness, mag., m_v	$>10^{-16}$ W/cm^{-2}	$>10^{-18}$ W/cm^{-2}	$>10^{-17}$ W/cm^2						$>10^{-16}$ to 10^{-18} W/cm^2	$>10^{-16}$ to 10^{-18} W/cm^2
Observation Field of View	$(1.2\times10^{-3})\times(2.9\times10^{-4})$ rad (4 arcmin×1 arcmin)	(1.2×10^{-3}) to (1.9×10^{-5})*** (4 arcmin to 4 arcsec)	2.4×10^{-5} (6 arcsec)						Variable	1.3×10^{-3} to 1.9×10^{-5} (4 arcmin to 4 arcsec)
Pointing Accuracy, rad (arcsec)	2.9×10^{-4} (60)	$(5 \text{ to } 10)\times10^{-6}$ (1 to 2)	5×10^{-6} (1)						2.9×10^{-4}, 1×10^{-5} (60, 2)	5×10^{-6} (1)
Pointing Stability, rad/obs time (arcsec/obs time)	2.9×10^{-5} (~6)	5×10^{-6} (<1)	5×10^{-6} (<1)						2.9×10^{-5} (6)	5×10^{-6} (< 1)
Slew Rate, max., rad/sec (arcsec/sec)	11.6×10^{-4} (240) earth orb scan	17.4×10^{-4} (360)	17.4×10^{-4} (360)						11.6×10^{-4} (240)	17.4×10^{-4} (360)
Slew Rate, min., rad/sec (arcsec/sec)	5×10^{-6} (<1)	5×10^{-6} (<1)	5×10^{-6} (<1)						5×10^{-6} (< 1)	5×10^{-6} (< 1)
Pointing Hold Time, sec	Scan angle 3000	3000 to 14,400	3000 to 14,400						3000 to 14,400	3000 to 14,400
Data Requirements/Observation Cycle:										
Imaging Data		Aspect sensor 5×10^{-6} rad (~1 arcsec)	Aspect sensor 5×10^{-6} rad (~1 arcsec)						Aspect sensor 5×10^{-6} rad (~1 arcsec)	Aspect sensor 5×10^{-6} rad (~1 arcsec)
Desired Resolution Spatial	2.9×10^{-4} rad (1 arcmin) or better	2.9×10^{-5} rad (<6 arcsec)							2.9×10^{-5} rad (<6 arcsec)	2.9×10^{-5} rad (<6 arcsec)
Spectral			4.4×10^{-4} μm at 4 μm						$\frac{\lambda}{\Delta\lambda} = 2500$	$\frac{\lambda}{\Delta\lambda} = 9090$
Equiv. Image Format Size, mm		25.4×25.4**	25.4×25.4**						25.4×25.4**	25.4×25.4**
Picture Elements/Image										
Images/Data Set		1	1						1	1
Images/Second		1	1						1	1
Photometric Resolution, %, bits		10^{-4}, 7 (log)	10^{-4}, 7 (log)						10^{-4}, 7 (log)	10^{-4}, 7 (log)
Equiv. Analog Data, MHz		11** or	11** or						11	11
Equiv. Digital Data, bits/image		7×10^6 **	7×10^6 **						7×10^6 **	7×10^6 **
Non-Imaging Data: Command Data, bps	32	32	32						32	32
Science/Exp. Data, bps	9376	200	1200						9376 (max)	9376 (max)
Housekeeping Data, bps	32	32	32						32	32
Special Requirements:										
Updating Cycle, Years	2	0.5	1						0.5 to 2	0.5 to 2
Mass, kg/yr (Weight, lb/yr)	4 (8.8)	10 (22)	80 (175)						93.5 (206)	93.5 (206)
Volume, m^3/yr (ft^3/yr)	1.42×10^{-2} (0.5)	2.83×10^{-2} (1)	7.1×10^{-2} (2.5)						11.35×10^{-2} (4)	11.35×10^{-2} (4)

*Vehicle Pointing Accuracy

**Aspect sensor data relayed to O/R experiment operations center for brief periods of time.

***Selected elements of detector array may be used to restrict effective field of view.

6.4.3.6 Available Background Data

a. A Half-Wave Number Michelson Interferometer Operating at Cryogenic Temperatures for the Spectral Region 5 to 15 microns, by James Engel, Geert Wijntzes, Block Engr, 19 Blackstone St., Cambridge, Mass., 02139 and Andrew Potter, Manned Spacecraft Center, NASA, Houston, Texas, April 1970.

6.5 FPE INTERFACE, SUPPORT, AND PERFORMANCE REQUIREMENTS

Table 6-6 summarizes the combined effect of the interface, support, and performance requirements of the individual experiments.

6.6 POTENTIAL MODE OF OPERATION

From the contamination viewpoint, the IR telescope would be best operated in a free-flying mode away from the contaminant cloud of the Space Station. However, if contaminant levels around the Space Station or supporting shuttle vehicle can be kept down, the IR telescope and its cooling equipment may be mounted on the Space Station (on shuttle vehicle) above a servicing airlock or in an attached experiment module. The IR telescope should be mounted so that the center of its gimbal motion range coincides with nadir to enable easy selection of scanning or pointing angles.

The application of this telescope to each of the proposed mission modes is described in the following paragraphs.

6.6.1 MISSION A - LIMITED ON-ORBIT STAY TIME WITH SPACE SHUTTLE. The IR telescope would be quite useful in this mode. The objective of completing a total sky survey in the IR would be dropped, and emphasis would be placed on high-resolution observations of preselected targets. The telescope for this type mission would be of somewhat different design than one for extended observations.

6.6.2 MISSION B - EXTENDED ORBIT REVISITED PERIODICALLY BY A SHUTTLE. To complete a total sky survey in the IR, approximately 12 months would be required. This type mission could accomplish the total survey during the initial operation, and then dwell on high-resolution observation of preselected target during the remainder of its lifetime. Cryogenics would require resupply approximately every six months.

6.6.3 MISSION C - EXTENDED ORBIT IN CONJUNCTION WITH SPACE STATION. This mission is an extension of B with the added possibility of frequent maintenance intervals and a more readily accessible resupply of cryogenics. Contamination would be a problem, however. Even the smallest speck of dust in the field of view would appear as a bright IR star.

6.7 ROLE OF MAN

The role of man will encompass the following activities:

Preparation. After protective covers and supports are removed, and the optics and instrumentation have been examined for damage, the instrumentation is tested. The telescope will be delivered into orbit prechilled with liquid neon at 27.6° K. Contaminant monitors and IR background sensors of the detached vehicle will be activated and must show acceptable levels before telescope aperture cover is opened.

Alignment. Optical alignment is checked in the red portion of the visible spectrum; this satisfies shorter wavelength system requirements. An IR astronomical source of known size and spectral distribution is used for testing the interferometer portion of the instrumentation.

Calibration. A number of artificial IR sources, supplemented by stars, are used for calibration of the instrumentation. The built-in instrumentation consists of reference sources, radiometer, interferometer and solid-state detector matrix test sets. Test data output is in digital format and is routed via normal monitoring circuits. Also, an additional calibration and checkout test set will be available during maintenance periods for more detailed measurements.

Operation. Temperatures of the various parts of the instrument are monitored during observations, particularly during those in the far IR (100 μm to 1,000 μm). The calibration observation for the spectral region of interest is taken, then the actual observations for data, and then the calibration observations are repeated. This procedure ensures that the true conditions under which the data were collected are known, so that any necessary corrections can be applied during data reduction.

Scheduled Maintenance. The insulation should be inspected for damage or potential failure. It is desirable to check the state of the electronics and detectors. Although damage to the optics is not expected, it is of interest to observe changes in the surfaces. It is necessary to resupply cryogenic fluid after any maintenance to assure sufficient supply for the next operating period.

Unscheduled Maintenance. Unscheduled maintenance will be necessary if: (1) the insulation is severely damaged (meteoroid or other cause); (2) a portion of the detector or information transmission system fails; or (3) if the stabilization system fails.

6.8 SCHEDULES

Table 6-7 shows estimated schedules for development, fabrication and test of the IR telescope and presently defined experiments.

6.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

A cryogenics and optical laboratory capable of accepting the assembled IR telescope module and its accessories in both the room temperature and the 27.6° K telescope and 2° K instrument conditions is desired. Test and calibration sets are needed for each of the experiment instrument units. A typical space station and ground based control center operating position together with communication links and information processing equipment will enable integrated checkout tests and operations simulations.

6.10 SAFETY ANALYSIS

The necessity for collecting the gaseous neon as part of the IR telescope cooling cycle to avoid release during observations also leads to a need for safe gaseous cryogen collection and periodic venting process. The very low temperatures 2° K and 27.6° K of the liquid helium and liquid neon also present a cold "burn" or freezing type hazard. For a Space Station, mounting the proposed docking to an airlock (enabling pressurized access to the "docked" telescope instrument compartment) presents some leakage hazard. If the alternate elevator/retractor method is used to pull the telescope and its gimbals into a pressurizable service housing, then man needs to avoid the gimbal mechanisms during tests. In a free-flying vehicle, two compartments may be provided, one of which should be a pressurizable compartment enabling access to all parts of the telescope

6.11 AVAILABLE BACKGROUND DATA

a. Orbital Astronomy Support Facility (OASF) Study, NAS8-2103, McDonnell-Douglas Corporation, Huntington Beach, California, 28 June 1968

b. H. L. Johnson and A. B. Meinel, An All-Sky Survey for Far-Infrared Radiation (50 μm - 800 μm) Associated with High Energy Phenomena, University of Arizona, Tucson, Arizona, 85721; MIT, Cambridge, Mass. 02142; ASE, Inc., Cambridge, Mass. 02142; 27 May 1970

Table 6-7. Schedules

Facility Item or Experiment	YEARS 7	6	5	4	3	2	1	▼ Launch 0	1	2	3	4
IR Telescope	Phase A	B	C	D								
Cooling Equipment	A	B	C	D								
Detector Array	A	B	C	D								
Radiometer (techniques for using selected detector array elements)	A	B	C	D								
Michelson Interferometer	A	B	C	D								
Aspect Sensor	A	B	C	D								